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DEPARTMENT OF AGRICULTURE.

RESULTS

OF

FIELD EXPERIMENTS

WITH

VARIOUS FERTILIZERS.

BY

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RESULTS OF FIELD EXPERIMENTS WITH VARIOUS FERTILIZERS.

INTRODUCTION.

The objects of the present article are:

1. To describe a series of experiments conducted on similar plans, but under widely varying conditions, by some hundreds of scientific and practical agriculturists in all of the older and some of the newer States of the Union.

2. To set forth the main results of these experiments, and the inferences to be derived from them.

3. To suggest plans for further experiments under the auspices of the United States Department of Agriculture.

In introducing the subject, it may be well to briefly recapitulate some of the main results of the experiments. I may perhaps be permitted to quote from an address delivered at a convention held at the Department of Agriculture in January, 1882:

> Farmers, from Canada to Texas, are spending millions upon millions of dollars every year for guano, fish scrap, ammoniated superphosphates, nitrate of soda, and the like. Ostensibly, they are buying the fertilizers at from $20 to $100 per ton. Actually, they are buying nitrogen at from 15 to 40 cents per pound. But need the farmer spend so much for nitrogen? Or might he use more with profit? These are questions that no professor of agriculture can answer. Indeed, no chemist or botanist to-day can so much as tell him how the different plants he cultivates stand related to nitrogen, for what ones he must buy it, and what ones he may use in his rotation to gather it from nature's stores and furnish it to him without money and without price save the cost of tillage.
>
> The question of the nitrogen supply is only one of a great many whose solution is most urgently demanded. We must know how to feed our plants, or go without food ourselves. We need more light. Some must come from the laboratory and the greenhouse; some must be sought in the field.
>
> Five years ago, while director of the Connecticut agricultural experiment station, I suggested some field experiments with fertilizers to be carried out by farmers for the purpose of studying the needs of their soils and the best materials to supply them. The outgrowth of these, in the form of extended series of experiments during four successive seasons, has been stated briefly in the American Agriculturist, and, in more detail, in the Reports of the Connecticut Board of Agriculture for 1877, 1878, 1879, and 1880. The experiments of 1881 have not yet been published in detail, but a few of the more important results will be given herewith.
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> With the sets of experimental fertilizers were sent blanks on which any who should choose were invited to send reports of their experiments. Nearly three hundred experiments have been reported. They come from colleges, experiment stations, and individual farmers in all the States east and from some west of the Mississippi, and from several of the British provinces. The quality of the work, as indicated by the reports, is most gratifying.

NEED OF MORE INFORMATION.

Hitherto we have been compelled to rely mainly upon European investigations for our facts regarding the nutrition of plants and the action of manures. Our information is incomplete, and even the foremost teachers may give us wrong counsel.

Dr. J. B. Lawes, of Rothamsted, England, unquestionably the foremost field experimenter in the world, in writing, in 1873, to the treasurer of the Massachusetts Society for the Promotion of Agriculture, said: "The best possible manure for all graminaceous crops—wheat, barley, maize (corn), oats, sugar-cane, rice, and pasture grass—is a mixture of superphosphate and nitrate of soda. * * * Potash is generally found in sufficient quantities in soils, and the artificial supply is not required." In more than half of our experiments with corn, and in nearly all with potatoes, the crops have been materially aided by potash salts, and without potash in the fertilizer they have often failed. The mixture which Dr. Lawes regards as "the best possible manure" for corn was sometimes very useful, and sometimes brought almost no return. The potash, which his experience in England led him to consider superfluous, was here, in many cases, the most necessary of all the fertilizing ingredients.

Several years ago the professor of agriculture of one of our leading agricultural colleges proposed a series of formulas for different crops. With the rest was one for corn, which, with a moderate proportion of potash and a small amount of phosphoric acid, supplied nitrogen at the rate of 64 pounds and at a cost of over $15 per acre.

Professor Ville, of France, whose theories of plant nutrition and formulas for fertilizers have been very widely published and followed in Europe and the United States, proposes also a formula for corn, which would cost from $19 to $27, and containing at a cost of from $5 to $9 per acre, according to the kinds of materials employed.

Both of these gentlemen thus assumed that to raise corn successfully will require large and costly supplies of nitrogen. The question whether corn can gather its own nitrogen, like clover, or demands an artificial supply, like wheat, whether it is an "exhausting" or a "renovating" crop, has been much discussed. Upon its answer depends the success of corn-growing in our older States. The experiments referred to bear emphatic testimony upon this point. The corn has almost uniformly refused to respond to nitrogen in fertilizers, and persists in getting on well without any artificial supply. But it has been largely benefited by phosphoric acid, and often by potash. The formulas above, with their large and excessively expensive amounts of nitrogen, would, in nearly every case, have involved great waste of both fertilizer and money.

VARIATIONS IN DEMANDS OF DIFFERENT SOILS FOR PLANT-FOOD.

Another outcome of these experiments which seems to me especially useful, is found in the very forcible illustration they give to the differences of soils, as regards their deficiencies of plant-food, and the effects of different fertilizing materials used upon them. In some places, phosphoric acid; in others, potash; in others, nitrogen; in others, lime; and in still others, several or all of these ingredients have proven indispensable in fertilizers to secure the growth of crops.

Mr. W. I. Bartholemew, of Putnam, Conn., has been conducting the experiments for five years. In every trial every plot which has received phosphoric acid has given a more or less satisfactory return, and every one without phosphoric acid has failed. Nitrogen and potash have each increased the yield of corn, but neither has brought enough increase to pay its cost, and the loss has been larger or smaller, as more or less was used. Potatoes, on the other hand, have responded profitably to all the ingredients named.

Mr. C. Sage, of Middletown, Conn., has had a very different experience. The phosphoric acid which Mr. Bartholemew finds so effective helps his plants but very little. Nitrogen proves as inefficient with him as with Mr. Bartholemew. But potash, which on Mr. Bartholemew's land had scarely any effect. proves with Mr. Sage decidedly the most effective ingredient. One hundred and fifty pounds per acre of muriate of potash, which costs Mr. Sage $3.50, has made a difference between corn so poor as to be hardly worth husking, and 60 bushels or more of excellent shelled corn per acre, and a fine growth of stalks.

Mr. W. C. Newton, of Durham, Conn., has a still different experience. Potash is as useless on his land as on Mr. Bartholemew's; phosphoric acid has no more effect than with Mr. Sage, but the nitrogen which both the latter gentlemen found so inefficient, is on Mr. Newton's soil the most efficient of all. Corn responds uniformly and largely to nitrogen in every form and on every plot where Mr. Newton has used it. The yield rises and falls regularly with the amount of nitrogen applied, and the same results have been obtained in different experiments in different seasons, in the same field. Mr. Newton's experience, however, is an exception, and an unusual one.

But while in the three cases above mentioned individual ingredients were profitable, and the so-called "complete fertilizers" were not warranted by the experience, in other cases all of the fertilizing ingredients named have been found necessary, and the omission of either is followed by a loss of produce.

Thus Mr. Fairchild, Middletown, Conn., finds the complete fertilizer most profitable in every case. Whenever he omits any of the important ingredients a small yield results. Mr. Fairchild further finds that the amount and form of combination of the fertilizing ingredients are important matters, and his experiments are showing him in what forms and ways they may be most advantageously used.

And, finally, there are many cases in which no artificial supply of plant-food brings a profitable return. Some soils will give good returns if manured, and others, without previous draining, irrigation, amendment by tillage, use of lime, marl, or otherwise, will not.

Artificial fertilizers, rightly used, must become, as indeed they already are getting to be, among the most potent means for the restoration of our depleted soils; but we do not yet know how to use them, and it is necessary, not only that new facts shall be learned, but that those

already known shall be better understood. For both these purposes I believe the experiments referred to are eminently useful.

SUGGESTIONS FOR EXPERIMENTING.

With reference to experiments with fertilizers the present article urges that it is only by selecting specific and narrow questions, and working at them systematically and continuously, that we shall secure the most valuable results. There has been too much firing at random. We need to choose proper points of attack, be sure of our aim, and concentrate our fire until a breach is made, and we need not only to work rightly, but to work together. Experiments with a common object, on a common plan, conducted by intelligent and careful investigators in different places, under different and actually observed and recorded conditions, are needed to bring the results which scientific agriculture so pressingly demands.

I have ventured to add further two suggestions; the first, and a perfectly obvious one is, that to get the most complete results, we need—

I. Field experiments, to include—

a. The culture of plants on plots of land treated with different manures, and careful weighings and measurements of produce.

b. Where practicable, chemical and physical studies of the soil.

c. In many cases, chemical analyses of the plants.

II. Pot experiments, in which the conditions can be definitely known and controlled, and the needed studies of soil and plants be carried out with equal or greater convenience and accuracy.

The second is, that there ought to be in the various sections of the country chemical and physical surveys of the land in the behalf of agriculture, as there have been topographical and geological surveys in the behalf of other industries and interests. And in fact this is precisely the direction in which we are tending in this experimental work.

PLAN OF THE PRESENT ARTICLE.

In this attempt to collate and set forth the results of the work of so many intelligent and earnest experimenters, it has been necessary to omit much material that would have been of interest had we space for its description, and to condense as much as possible the accounts that are given. The arrangement of topics is in brief as follows:

1. Explanations of special experiments upon the question of the nitrogen supply.
2. Explanations of so-called general experiments.
3. Notes upon individual experiments.
4. General discussion of experiments.
5. Results and practical applications.
6. Plans for co-operative experiments.
7. The details of results in the form of tables, &c., in the appendix.

EXPERIMENTS UPON NITROGEN SUPPLIES.

The experiments of which it is proposed to give an account here are so numerous that detailed descriptions of the work of individual experimenters, except in a few cases, would be hardly practicable. I will therefore attempt to group them in three classes, and describe the several classes separately:

1. Special nitrogen experiments, including a number which have had for their object the study of the feeding capacities of plants, with especial reference to the nitrogen supply.

2. General experiments which were proposed primarily for testing the wants of soils and crops and the best means of supplying them; but which, being on a common plan and large in number, likewise afford data of great value.

3. Other experiments, on plans which, though different from the above, are sufficiently similar to them to allow of comparison.

These have been performed by a number of professors in agricultural colleges, and intelligent, practical farmers in several States. The specific questions upon which information is sought in the experiments may be stated thus:

1st. How do the plants experimented with get on with the "mineral" fertilizers, such as are supplied by superphosphates and potash salts?

2d. More especially, how do they respond to nitrogen when added, in different forms and amounts, to the mineral fertilizers?

3d. And, finally, what inferences may we draw as to the feeding capacities of the plants, their power to gather their food from soil and air, and the effects of different materials upon their growth, especial reference being made to the nitrogen supply?

For the systematic study of these questions a special "nitrogen experiment" was devised in 1878, and conducted by several gentlemen. Similar series were repeated in 1879, and with some variations in 1880. The plan and purpose of the experiments are set forth in the following statements from a four-page circular, which was sent to the experimenters of 1881, similar ones having been prepared for those of previous years.*

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* In the tabular statements of results of the experiments (Appendix, Tables I, II, and III), some differences will be noticed between the schedules of 1881 and those of the previous seasons.

In the experiments of 1881 nitrogen is supplied in Group IV as ammonia, and in Group V as organic nitrogen, while in the experiments of 1878 and 1880, as may be seen in Table I, the nitrogen is supplied in Group IV as "nitrogen" mixture, and in Group V in other forms. A further difference is found in Group V, which, in 1878 and 1880, supplied the nitrogen as a two-third ration, but in 1881 in varying quantities.

Another year's experience has suggested some slight changes in the quantities of phosphoric acid and potash, the former being somewhat increased and the latter diminished, as will be seen by reference to the schedule of special nitrogen experi-

SPECIAL EXPERIMENTS FOR NITROGEN TESTS. 1881—EXPLANATIONS.

The object of this experiment is to test the effects of nitrogenous fertilizers in different amounts and combinations upon the growth of the plant, and inferentially its capacity to gather its nitrogen from natural sources.

The fertilizers.—The ingredients and amounts are such as are used in ordinary practice, phosphoric acid and potash being supplied in about the proportions that occur in a corn crop of fifty or sixty bushels, and nitrogen in one-third, two-thirds, and full amount in same crop.

Forms of nitrogen.—The nitrogen is supplied as nitric acid in nitrate of soda: as ammonia in sulphate of ammonia, and as organic nitrogen in dried blood.

Quantities of nitrogen.—The nitrogen is applied at the rate of 24 pounds per acre in "one-third ration"; 48 pounds per acre in "two-thirds ration"; and 72 pounds per acre in "full ration."

Arrangement of plots and fertilizers.—The ingredients are supplied as:

Partial fertilizers.	Group I, Nos. 1–3. Each by itself. Group II. Nos. 4–6. Two by two.	Thus testing the effects of ingredients separately and capacity of soil.
Complete fertilizers.	Group III, Nos. 7–9. Nitrogen as nitric acid in nitrate of soda............ Group IV, Nos. 10–12. Nitrogen as ammonia in sulphate of ammonia.. Group V, Nos. 13–15. Nitrogen as organic nitrogen in dried blood......	Nitrogen in one-third, two-thirds, full ration.

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ments in the chapter beyond on proposed plans for co-operative experiments. It seems to me that this latter schedule and that of 1882, in the light of past experience, is well adapted to its purpose, and will very likely be continued for some time to come.

EXPERIMENTAL FERTILIZERS—SPECIAL NITROGEN SET, 1881.

No.	Materials.	Amounts. Acre set for $\frac{1}{20}$ acre plots.	Amounts. Two-acre set for $\frac{1}{10}$ acre plots.
		Pounds.	*Pounds.*
1	Nitrate of soda	7½	15
2	Superphosphate	15	30
3	Muriate of potash	7½	15
4	Nitrate of soda	7½	15
	Superphosphate	15	30
5	Nitrate of soda	7½	15
	Muriate of potash	7½	15
6	Superphosphate } Mixed minerals	15	30
	Muriate of potash } Mixed minerals	7½	15
7	Mixed minerals, as No. 6	22½	45
	Nitrate of soda	7½	15
8	Mixed minerals, as No. 6	22½	45
	Nitrate of soda	15	30
9	Mixed minerals, as No. 6	22½	45
	Nitrate of soda	22½	45
10	Mixed minerals, as No. 6	22½	45
	Sulphate of ammonia	5⅝	11¼
11	Mixed minerals, as No. 6	22½	45
	Sulphate of ammonia	11¼	22½
12	Mixed minerals, as No. 6	22½	45
	Sulphate of ammonia	16⅞	33¾
13	Mixed minerals, as No. 6	22½	45
	Dried blood	11¼	22½
14	Mixed minerals, as No. 6	22½	45
	Dried blood	22½	45
15	Mixed minerals, as No. 6	22¾	45
	Dried blood	33¾	67½
6*a*	Superphosphate } Mixed minerals	15	30
	Muriate of potash } Mixed minerals	7½	15
6*b*	Superphosphate } Mixed minerals	15	30
	Muriate of potash } Mixed minerals	7½	15
6*c*	Superphosphate } Mixed minerals	15	30
	Muriate of potash } Mixed minerals	7½	15

Nos. 6*a*, 6*b*, and 6*c* are simply duplicates of mixed minerals No. 6.

This schedule provides for twenty plots, of which two are unmanured, and eighteen supplied with the experimental fertilizers.

No. 6, the mixture of superphosphate and muriate of potash, is designated as "mixed minerals." This is duplicated in Nos. 6*a*, 6*b*, and 6*c*. The same mixture forms the basis of Nos. 7 to 15, inclusive, which consist of "mixed minerals," with the addition of nitrogen compounds.

The fertilizers were supplied, in part at cost and in part gratuitously, by the Mapes Formula and Peruvian Guano Company, to whose interest and enthusiasm in promoting the experiments especial thanks are due.

Each set of experimental fertilizers was accompanied by directions for use (see above) and a blank, on which the experimenters were requested to record their observations and the results obtained.

The blanks were sheets of paper 12 by 19 inches in size, with spaces for numerous details as to soil, weather, culture, produce, &c. The details provided for were very similar to those set forth in the report of the experiments by Mr. Atwood, in the chapter beyond, on the subject of general experiments. The general plans and directions for the experiments are the same as set forth in the chapter on plans for co-operative experiments beyond.

The following is a list of experimenters and experiments on the above schedules reported to the writer. Some others, notably one by Prof. H. C. White, of the College of Agricultural and Mechanic Arts, and the Agricultural Experiment Station at Athens, Ga., were not reported, having, as I understand, been so injured by drouth and accidents as to make their publication less desirable:

A. 1878.—Prof. J. R. FARRINGTON, Maine Agricultural College, Orono. *Corn.*

B. 1878.—W. I. BARTHOLEMEW, Putnam, Conn. *Corn.*

C. 1879, '80, and '81.—As above. *Corn* and *potatoes*, side by side.

D. 1878.—CHESTER SAGE, Middletown, Conn. *Corn.*

E. 1879.—As above. *Corn.*

F. 1879.—Col. J. B. MEAD, Randolph, Vt., under the auspices of the University of Vermont and State Agricultural College. *Corn.*

G. 1880.—Prof. W. H. JORDAN, Maine Agricultural College, Orono. *Corn.*

H. 1880.—EDWARD HICKS, Old Westbury (L. I.), N. Y. *Corn.*

I. 1880.—CHARLES FAIRCHILD, Middletown, Conn. *Corn.*

J. 1881.—As above. *Oats and potatoes*, side by side.

K. 1880.—WILLIAM C. NEWTON, Durham, Conn. *Corn.*

L. 1881.—As above. *Corn.*

M. 1881.—Prof. C. L. INGERSOLL, Purdue University, La Fayette, Ind. *Corn* and *potatoes*, side by side.

N. 1881.—C. E. THORNE, Ohio State University, Columbus, Ohio. *Corn.*

O. 1881.—J. W. PIERCE, West Millbury, Mass. *Corn.*

P. 1881.—EDWARD HICKS, Old Westbury, N. Y. *Corn.*

Q. 1881.—Prof. SAMUEL JOHNSON, Michigan Agricultural College, Lansing, Mich. *Corn.*

R. 1881.—Prof. W. C. STUBBS, Alabama Agricultural and Mechanical College, Auburn, Ala. *Cotton.*

S. 1881.—J. M. MANNING, Taunton, Mass. *Clover.*

The main results of the special nitrogen experiments are stated in the appendix tables I, II, and III. Details of the reports are also given in the appendix.

The following account of Mr. Fairchild's experiments in 1881 with oats and potatoes will serve to illustrate the plan and results.

It will be noticed that the arrangement of the groups with the nitrogenous fertilizers is slightly different from that mentioned above. The experiments were commenced in 1879, and on a schedule which has been slightly altered for the experiments of succeeding years, as already explained.

EFFECTS OF NITROGENOUS FERTILIZERS

EXPERIMENTS WITH OATS AND POTATOES IN 1881. BY MR. CHARLES FAIRCHILD, OF MIDDLETOWN, CONN.

[SOIL, dark loam, loam subsoil, moist; had oats in 1877, rye in 1878, grass in 1879, and corn fertilized as below in 1880.]

	Kind and amount of fertilizers per acre.	Yield per acre. Oats.			Increase per acre. Oats.			Cost of fertilizers, freight, &c.	Pecuniary results. Val. of increase.		Grain.	
		Grain.	Straw.	Potatoes.	Grain.	Straw.	Potatoes.		Oats.	Potatoes.	Oats.	Potatoes.
		Bush.	Lbs.	Bush.	Bush.	Lbs.	Bush.					
0	No manure	26.9	1,180	28.0	......	......	......				......	......
1	Nitrogen mixture, 150 pounds	38.1	1,820	42.0	11.3	627	13.3	$6 00	$9 75	$9 98	$3 95	$3 98
2	Superphosphate, 300 pounds	33.8	1,800	56.0	6.9	607	27.3	6 00	7 42	20 48	1 42	14 48
3	Muriate of potash, 150 pounds	31.3	1,720	60.0	4.4	527	31.3	3 75	5 50	23 48	1 75	19 73
4	Nitrogen mixture, 150 pounds, and superphosphate, 300 pounds	51.9	2,660	94.7	25.0	1,467	66.0	12 00	22 55	49 50	10 55	37 50
5	Nitrogen mixture, 150 pounds, and muriate of potash, 150 pounds	42.5	2,160	68.0	15.6	967	39.3	9 75	14 40	29 48	4 65	19 73
6	Superphosphate, 300 pounds, and mur. of pot., 150 pounds, "mixed minerals"	33.8	2,280	90.7	6.9	1,087	62.0	9 75	10 30	46 50	55	36 75
7	Mixed minerals (as No. 6), 450 pounds, and nitrate of soda, 150 pounds	54.4	3,500	124.7	27.5	2,307	96.0	15 75	28 97	72 00	13 22	54 25
8	Mixed minerals, 450 pounds, and nitrate of soda, 300 pounds	59.4	3,860	138.7	32.5	2,667	110.0	21 75	33 88	82 50	12 13	60 75
9	Mixed minerals, 450 pounds, and nitrate of soda, 450 pounds	59.4	4,380	120.0	32.5	3,107	91.3	27 75	36 52	68 40	8 77	40 65
6a	Mixed minerals (as No. 6), 450 pounds	36.3	1,760	94.0	9.4	567	65.3	9 75	8 56	48 98	1 19	39 23
00	No manure	27.5	1,280	46.7	......	......	......	......	......	......	......	......
10	Mixed minerals, 450 pounds, and nitrogen mixture, 150 pounds	51.9	3,140	122.7	25.0	1,947	94.0	15 75	25 43	70 50	9 68	54 75
11	Mixed minerals, 450 pounds, and nitrogen mixture, 300 pounds	55.6	3,380	144.7	28.8	2,187	116.0	21 75	28 93	87 00	7 10	65 25
12	Mixed minerals, 450 pounds, and nitrogen mixture, 450 pounds	59.4	3,780	144.7	32.5	2,587	116.0	27 75	33 40	87 00	5 65	59 25
6b	Mixed minerals (as No. 6), 450 pounds	33.8	1,760	110.0	6.9	567	81.3	9 75	7 18	60 98	2 57	51 23
13	Mixed minerals, 450 pounds, and sulphate of ammonia, 225 pounds	61.9	3,700	135.3	35.0	2,507	106.6	21 75	34 29	79 95	12 54	58 20
14	Mixed minerals, 550 pounds, and dried blood, 450 pounds	53.8	3,080	134.7	26.9	1,887	106.0	21 75	26 10	79 50	4 35	57 75
15	Peruvian guano, 450 pounds, and muriate of potash, 150 pounds	54.4	2,980	133.3	27.5	1,787	104.6	21 75	25 85	78 45	4 10	56 70
16	Mixed minerals (as No. 6), 450 pounds	35.0	1,760	96.0	8.1	567	67.3	9 75	7 87	50 48	1 88	40 73
000	No manure	26.3	1,120	29.3	......	......	......	......	......	......	......	......
A	Bone, 150 pounds	31.3	1,680	54.0	4.4	487	25.3	3 00	5 33	18 98	2 33	15 98
B	Bone, 150 pounds, and muriate of potash, 100 pounds	35.0	1,960	74.0	8.1	767	45.3	5 50	9 07	33 98	4 57	28 48
C	Same as B, and sulphate of ammonia, 100 pounds	45.6	1,980	......	18.8	787	......	10 75	15 03	......	4 28	......

The plots were parallel strips of eight square rods each. In 1880 corn was planted over the whole field. In 1881 the whole was divided into halves by a line crossing the plots, and one-half devoted to oats and the other half to potatoes. Mr. Fairchild proposes to follow with wheat and grass, thus running the experiment through a regular rotation of several years, the same fertilizers being applied to the same plots year after year, while the crops succeed each other as in ordinary farm practice. The cost of the fertilizers includes $5 per ton for freight and applying. Potatoes are estimated at 75 cents per bushel, oats at 55 cents, and oat straw at $12 per ton, which are fair rates for the region and season.

Before discussing these special experiments, a description of the other experiments will, perhaps, be in place.

GENERAL EXPERIMENTS.

SOIL TESTS WITH FERTILIZERS.

While director of the Connecticut Agricultural Experiment Station some years since the writer was in constant receipt of questions like the following, nor have they since ceased to come:

I have a piece of old land that has been somewhat worn down by a number of years' cropping. It is such and such a kind of soil, has been treated so and so, and I want to get such a crop, and at the same time bring it into good condition. My supply of stable manure is short. Will it pay for me to try guano, or superphosphate, or potash salts? Will you be kind enough to give me a proper formula for a fertilizer for corn?

Unable, of course, to answer the inquiries I suggested some experiments by farmers for the purpose of learning which of the more costly ingredients of fertilizers were demanded by their soils and crops, and how they could be most economically supplied.

The purpose of the experiments is stated in the following extract from the report of that station for 1876:

One of the fundamental results of the vast amount of work done in field experiments with fertilizers is the clear demonstration that soils vary greatly in their capabilities of supplying food to crops, that different ingredients are deficient in different soils, and that the teachings of any given experiment are in the main applicable only to the particular kind of soil on which it is made.

For farmers who have not their own experience, or that of others in like circumstances, to guide them, the most sensible method for determining what are the deficiencies of their soils, and how they will be the most economically supplied to given crops, is to try experiments on a small scale; to put the question to the soil with different fertilizing materials and obtain its reply in the crops produced.

This is no new idea. It has been urged again and again by the leading agricultural chemists in this country and in Europe. Stoeckhardt, Knop, and Wolff, in Germany, Ville, in France, Voelcker, in England, and Johnson, in this country, have all not only urged upon farmers the importance of such experiments, but given specific suggestions for conducting them.

The report of the Connecticut Board of Agriculture for 1877 contains an account of a number of field experiments with fertilizers made in accordance with this suggestion. At the request of the American Agriculturist, plans for similar experiments, with such alterations as experience had suggested, were drawn up and proposed by that journal to its readers in the spring of 1878. At the same time the University of Vermont and State Agricultural College and the Maine State College of Agriculture and Mechanic Arts introduced similar field trials, the latter upon its own farm, the former through the agency of a number of leading farmers of Vermont. The American Agriculturist not only proposed the experiments to its readers, but, with the hearty co-operation of several prominent dealers in fertilizers, arranged to provide the materials at prices just covering the cost. With each lot of fertilizers

were sent explanations and directions for the experiments, and blanks on which such of the experimenters as might care to take the needed trouble were requested to report the results.

The experiments have been made from Maine to Kansas, and from Canada to Florida. The total number I have no definite means of learning. Between 250 to 300 reports, however, have been sent to me for examination. As an application of science to farming by practical men who get their living by the labor of their brains and hands, and who have not only found in them a means of testing the needs of their soils and the ways of supplying them, but have also, by working together on a common plan, made an important addition to the sum of our knowledge of the way in which soils furnish plant food, and plants use it, and, what seems to me of more importance, have thus been able to make their farming more a labor of the mind than the hands. The work has been, I feel, of the greatest usefulness.

In explaining the details of plans and experiments, I quote, with some alterations, from one of the reports referred to:

PURPOSE AND PLAN OF THE EXPERIMENTS.

The ostensible object of these experiments was to work upon farmers' soils. Underneath this lay, in my own thought, a deeper purpose to work upon their owners' minds. And in this regard especially, the outcome has been most gratifying.

The vast amount of work done in field experiments with fertilizers has clearly demonstrated the facts that:

1. Soils vary greatly in their capabilities of supplying food to crops. Different ingredients are deficient in different soils.

2. Soils fail to furnish enough food to crops, not so much because they have not abundant stores, as because the materials are not in available forms.

3. Deficiencies in many soils are due more to their physical condition, their texture and relations to heat and moisture, and to their lack of absorptive power, the power to hold plant food and not allow it to be leached away beyond the reach of the roots of the plants, than to their lack of plant food. Such soils want amendments first and fertilizers afterwards. Tillage improves the mechanical condition of the soil, while it also aids in rendering plant food available.

4. The chief office of fertilizers is to supply the plant food which crops need and soils fail to furnish.

5. But the indirect action of fertilizers in improving the mechanical condition of the soil, increasing its absorptive power, and rendering its stores of plant food available, is often of much more consequence than their direct action in supplying plant food. Hence cheap materials, like lime and plaster, are often more profitable than farm manures or artificial fertilizers.

6. Plants vary greatly with respect to their capabilities for gathering their food from soil and air. Hence the proper fertilizer in a given case depends upon the crop as well as upon the soil.

7. It may be regarded as pretty well settled that the only ingredients of plant food which we need to consider in commercial fertilizers are *potash, lime, magnesia, phosphoric acid, sulphuric acid, and nitrogen.* Of this list the magnesia is commonly, though not always, supplied in sufficient quantities in even "worn-out" soils. Sometimes its presence in fertilizers may be of considerable importance to crops. Sulphuric acid and lime are more often deficient, and hence one reason of the good effect so often observed from the application of lime and plaster. The remaining substances, the *phosphoric acid, nitrogen, and potash,* are the most important ingredi-

ents of our common commercial fertilizers, because of both their scarcity in the soil and their high cost. It is in supplying these that guano, phosphates, bone manures, potash salts, and most other commercial fertilizers are chiefly useful.

8. It is not good economy to pay high prices for materials which our soils may themselves furnish, but it is good economy to supply the lacking ones in the cheapest way.

9. The only way to learn what materials are proper in a given case is by observation and experiment. The rational method for determining what ingredients of plant food a soil fails to furnish in abundance, and how these lacking materials can be most economically supplied, is to put the question to the soil with different fertilizing materials and get the reply in the crops produced.

10. The results of any given experiment are, in the main, applicable only to the particular case where it is made.

11. A single season's experimenting does not tell the whole story. To get complete results the trials must be carried through a series of years and crops.

To test the needs of the soils with respect to the chief ingredients of chemical fertilizers, phosphoric acid, nitrogen, and potash was the special and the action of different fertilizing materials the general object of these experiments.

THE FERTILIZERS USED IN THE EXPERIMENTS.

Fertilizing materials were chosen which contain nitrogen, phosphoric acid, and potash, in forms shown by general experience to be appropriate and advantageous for use, to wit:

Nitrate of soda, to furnish nitrogen.

Superphosphate, to furnish phosphoric acid (with sulphuric acid and lime).

Muriate of potash, to furnish potash.

Land plaster, to furnish sulphuric acid and lime.

The several materials in small bags were put up in sets. One, called "acre set," contained ingredients as below:

FERTILIZING MATERIALS.

ACRE SET.

Bag No.	Kind.	Amount.	Valuable ingredients.	Per 100 pounds.
		Pounds.		*Per cent.*
A	Nitrate of soda	20	Nitrogen	15
B	Dissolved bone black	30	Phosphoric acid	15
C	Muriate of potash	20	Potash	50
D	Nitrate of soda	15	Nitrogen	5
	Dissolved bone black	30	Phosphoric acid	10
E	Nitrate of soda	15	Nitrogen	6.42
	Muriate of potash	20	Potash	28.57
F	Dissolved bone black	30	Phosphoric acid	9
	Muriate of potash	20	Potash	20
G	Nitrate of soda	15	Nitrogen	3.46
	Dissolved bone black	30	Phosphoric acid	6.92
	Muriate of potash	20	Potash	15.38
H	Plaster	20		

The contents of each bag of the "acre set" were intended for a plot one-tenth of an acre. The eight plots thus fertilized, with two unmanured, thus make one acre. This "acre set" was furnished for $8.30.

Another "half-acre set" contained similar materials, but in half above amounts, was also supplied at a cost of $5. The "acre-set" was most strongly recommended, and was used by the majority of experimenters. Later experience, however, has led me to question whether for ordinary farmers, the smaller experiments with plots of one-twentieth instead of one-tenth acre, are not preferable. Another outcome of the experience has been a slight modification in the quantities of the materials, and in the increase of phosphoric acid and decrease of nitrogen and potash, as will be explained later on. These sets furnished materials in amounts, and at costs per acre, as below. The costs are reckoned at market prices, with an addition of $5 per ton for freight and handling. Of course the prices fluctuate materially, so that these could not be taken as a standard:

EXPERIMENTAL FERTILIZERS.

Number of bag.	Fertilizer used.				Furnishing valuable ingredients.			
	Kind.	Pounds per acre.	At price per ton.	Cost per acre.	Kind.	Amount per cent.	Pounds per acre.	Cost per acre.
A	Nitrate of soda	200	$75 00	$7 50	Nitrogen	16.0	32.0	$7 50
B	Dissolved bone black	300	35 00	5 25	Phosphoric acid	16.0	48.0	5 25
C	Muriate of potash	200	45 00	4 50	Potash	50.0	100.0	4 50
D	Nitrate of soda	150	48 40	10 88	Nitrogen	5.3	24.0	5 63
	Dissolved bone black	300			Phosphoric acid	10.7	48.0	5 25
E	Nitrate of soda	150	58 00	10 13	Nitrogen	6.6	24.0	5 63
	Muriate of potash	200			Potash	28.6	10.0	4 50
F	Dissolved bone black	300	39 00	9 75	Phosphoric acid	9.6	48.0	5 25
	Muriate of potash	200			Potash	20.0	100.0	4 50
G	Nitrate of soda	150	47 32	15 38	Nitrogen	3.7	24.0	5 63
	Dissolved bone black	300			Phosphoric acid	7.4	48.0	5 25
	Muriate of potash	200			Potash	15.4	100.0	4 50
H	Plaster	200	8 00	80	......	......	......	80

The following is a reprint of a circular giving directions for the experiments:

DIRECTIONS FOR THE EXPERIMENTS.

"What is worth doing is worth doing well." You wish to learn something of value for yourself and do something that will be useful to others also. To this end, note:

The "condensed directions."—Take the slip bearing these in your pocket when you go to lay out the experiment, and read it on the ground.

The blank for report.—Look this over while the crop is growing, think what it asks for, make up your mind how to collect the facts (it will be well to get a little five-cent blank-book for notes to be made during the summer): if you can improve the plan do so, and accept thanks.

Don't say this is too much or too hard for you to do. The season is before you. You cannot use the time and mental effort, and really not a great deal of either is required, to better purpose.

EVERYTHING IN ORDER BEFORE STARTING.

1. Have your plans complete and clearly in mind, and everything ready before you start. Proper plans at the outset; uniform soil for all the experiments, and poor or

"worn-out" soils for the soil tests; plots of proper size, shape, and accurately laid out; right application of the fertilizers; good seed: careful measurement of crops; full notes of details; and careful observation of the effects of the fertilizers on succeeding crops, are essential to the best results.

SELECT UNIFORM SOIL.

2. Select soil as nearly uniform in quality as possible. There will be more or less variation in different parts of the same field at best. The less there is of this the more reliable will be the experiments. Level land should be chosen if practicable, but if it be sloping, let the plots run up and down the ascent so that any wash by rains will not transfer the materials from one plot to another. Of course the portion chosen for experiment should be a fair sample of the whole field.

"WORN-OUT" SOILS FOR SOIL TESTS.

3. For *soil tests* select poor or "worn-out" soils. You want to learn what the soil itself can do by its own natural strength, not what it will do with the aid of a store of plant food, which has been either accumulated by natural processes or left over from previous manuring, and will obscure the action of the fertilizers.

LAY OUT PLOTS ACCURATELY.

4. Lay out the whole experimental area and the individual plots as accurately as you can. Measure with chain or tape, if you have it, otherwise with pole marked in feet and inches. Drive good, strong stakes firmly into the ground at the boundaries so that you may be able to tell in this and coming seasons where the divisions are. Don't let the stakes get knocked over or plowed up.

LONG NARROW PLOTS.

5. Make the plots as long as practicable, so as to compensate as far as possible for the unevenness of the soil. To this end let the whole area be as long and narrow as convenient, and the plots run lengthwise through it. If the seed is to be planted in rows the length can be adapted to the distance of the rows apart. If this space is less than two and one-half feet an unmanured row had better be left between each two strips. In general, an unmanured strip at least two or three feet wide should be left between each two plots, so as to prevent the crop of one from being affected by the manure of another.*

If the soil is even, small, short plots will do. But generally it will not be even, and long strips are therefore safer. A good plan is to have *the whole area six times as long as it is wide.* For an area of one acre, 32 by 5 rods (= 160 rods) will make the length just about six times the width. The ten plots of one-tenth acre would thus be each 32 rods by ½ rod. See "condensed directions" for figures for calculating dimensions of plots.

FERTILIZERS WELL DIFFUSED THROUGH SOIL.

6. The fertilizers may be applied broadcast, or if more convenient, they may be put in the hill or drill, *provided they are well diffused through the soil.* To accomplish this, they had better be diluted with several times their bulk of earth before using. The important points are, that they be:

1st. Applied evenly over the plots where they belong and not allowed to get outside.

*With corn, either leave one unmanured row between each two plots or cultivate between the rows deep enough to cut the roots and prevent them from feeding on their neighbors' fertilizers. This "intercultural tillage" will do no harm and may be a decided benefit.

2d. Well distributed through the soil.

Experiments with concentrated fertilizers are often spoiled, just as crops are injured or lost through wrong application. Farmers are apt to think the manure must be put close to the seed or the plant will not get the benefit of it. This is wrong. It is not the just germinated plantlet that needs the manure, but the plant, from the time it is well started until its growth is done. We want, not only to give the crop a good start, but to help it out on the home stretch as well. The roots and their branching rootlets run out in all directions in search of food, and the fertilizers ought to be where as many of the rootlets as possible can get at them. If we distribute the fertilizers as well as we can, the water in the soil, aided by the chemical and physical forces that nature keeps in operation, will do the rest. In illustration of this, remember how well barn-manure acts when applied as a top-dressing long before the seed is put in.

But if we concentrate the fertilizers in one place, fewer roots will get them, and these may be injured by coming in contact with them or with their concentrated solutions in the soil. The roots will find their way to the manure and develop more where it lies, it is true: still we should not oblige them to huddle together in one place, but should rather encourage them to spread around, where, with the increased capacity the fertilizer gives them, they can get the more from the soil. Roots join with other natural agents in rendering inert stores of plant food available.

Above all, do not let the fertilizers come too close to the seed. A coarse, dilute material like yard manure may do the plants no harm, but such concentrated fertilizers as potash salts, dried blood, or high grade superphosphates may kill them.

Since, in these experiments, it is particularly important that the effect of each fertilizer be fairly tested, it would be well to *mix them with three or four times their bulk of mellow earth before applying.* If the latter is rich in vegetable mold, so much the better. Moist sawdust may be used in place of the earth, if more convenient. Do this by all means if applied in the hill or drill. It will be well to even off the ground by a shallow plowing, spread the fertilizers evenly over the plots, and then work them in with a good, deep-running harrow, or turn them under by very shallow plowing. When the plots are accurately staked out and the fertilizers carefully applied and worked in, the plow or harrow may be run across the plots without fear of transporting the fertilizers from one to another. Apply as long as possible before planting.

UNMANURED PLOTS FOR COMPARISON.

7. It is of the greatest importance that several unmanured plots be left for comparison. For eight manured plots, two unmanured will suffice; but where there are more than that, three, one at each side and the one in the middle, or, if the number is large, one in the middle and one half-way between this and each side would be advisable. You will have very little idea how uneven an apparently uniform soil may be until you make the trial.

OTHER FERTILIZERS TO BE TRIED.

8. It will be well to try other materials along with the experimental, &c. Guano, fish, ashes, farm-manures, and especially *lime* are to be recommended.

ARRANGEMENT OF PLOTS.

9. Arrangements like the following will be well:

Regular set.			Regular set and extras.		
Plot No.	Bag No.	Fertilizers.	Plot No.	Bag No.	Fertilizers.
0.	....	No manure.	0.	....	No manure.
A.	A.	Nitrogen.	A.	A.	Nitrogen.
B.	B.	Phosphoric acid.	B.	B.	Phosphoric acid.
C.	C.	Potash.	C.	C.	Potash.
D.	D.	Nitrogen and phosphoric acid.	D.	D.	Nitrogen and phosphoric acid.
E.	E.	Nitrogen and potash.	E.	E.	Nitrogen and potash.
F.	F.	Phosphoric acid. and potash.	00.	....	No manure.
G.	G.	Nitrogen, phosphoric acid, and potash.	F.	F.	Phosphoric acid and potash.
H.	H.	Plaster.	G.	G.	Nitrogen, phosphoric acid, and potash.
00.	00.	No manure.	H.	H.	Plaster.
			K.	....	Wood ashes.
			L.	....	Lime, freshly slaked, 60–75 lbs. on $\frac{1}{10}$ acre.
			M.	....	Farm manure.
			000.	....	No manure.

SEE THAT ALL IS DONE RIGHTLY.

10. Attend to the work yourself. Don't trust it to the hired man unless you are sure he will do it better than you can.

MAKE ACCURATE OBSERVATIONS.

11. Watch the experiments closely. Note your observations. Make them both as accurate and complete as you can. Put down your notes when you make your observations. Do not trust them to future recollection.

REPORTS.

12. Make your reports as full and accurate as possible. Keep one copy for your own future use, and send the other in so that your results may be compared and published with others in good season. The benefit will not be yours alone, but you will share with others the good that will come from the combined work of all.

THIS PROGRAMME IS NOT AS DIFFICULT AS IT SEEMS.

This may seem a pretty heavy programme for ordinary farmers. If you cannot follow the directions fully, come as near to them as you can. Of course the circumstances in which you work will require changes which your own good judgment will regulate.

A briefer set of directions was also supplied, as follows:

CONDENSED DIRECTIONS.

1st. Have your plans all made and everything ready before you start. Remember that poor soil for the soil tests, uniform soil for all, plots long and narrow and accurately measured and staked out, and right application of the fertilizers are essential to the best success. Don't forget the tape or pole for measuring, the stakes, and the earth for diluting the fertilizers if they are to be put in the hill or drill.

2d. Note on the back of this the dimensions you have determined upon for the whole field and for each plot.

3d. Select a fair average portion of the field to be tested, lay it out as accurately as you can, and put strong stakes firmly into the ground at the boundaries.

4th. Designate each plot by a number. A, B, C, &c., corresponding to the number of the fertilizer. Put a stake opposite each and tie a label to it with the number of the plot and kind of fertilizer. The tags on the bags will serve for labels.

5th. Distribute each fertilizer evenly over its plot, and do not let it get outside. Lay your plans for doing this in advance, otherwise you may find the fertilizer all used up before you get to the end, or have some left over. Remember what was said about mixing well with the soil, especially when put in the hill. If you do not you may kill some of the seed and injure the growth of the rest.

6th. Be as systematic and accurate as you can, not only in starting the experiments, but in carrying them out, and noting the results.

A long, narrow, experimental area, divided lengthwise in narrow strips. A good rule is to have the whole area six times as long as it is wide, or as near this as practicable.

ONE-TENTH ACRE PLOTS—LENGTH AND WIDTH.

To calculate size of plot of one-tenth acre (for "acre set") find in the left-hand column "width" the figure for the width you have decided upon, the opposite figure in the right-hand column will represent the length; or, given the length in the right-hand column, the opposite figure in the left-hand column will be the width. For one-twentieth acre plots ("half-acre set") take of course half the length for same width, or *vice versa*.

Width.	Length.			Width.	Length.		
Rods.	*Feet =*	*Rods.*	*Feet.*	*Rods.*	*Feet =*	*Rods.*	*Feet.*
One-third	792 =	48		Two-thirds	396 =	24	
Two-fifths	660 =	40		Three-fourths	352 =	21	5½
One-half	528 =	32		Four-fifths	330 =	20	
Three-fifths	440 =	26	11	One	264 =	16	
Feet.	*Feet =*	*Rods.*	*Feet.*	*Feet.*	*Feet =*	*Rods.*	*Feet.*
6	726 =	44		11½	379 =	23	
6½	670 =	40	10	12	363 =	22	
7	623 =	37	12	12½	349 =	21	2
7½	581 =	35	3	13	335 =	20	5
8	545 =	33		13½	323 =	19	9
8½	513 =	31	1	14	311 =	18	14
9	484 =	29	5	14½	300 =	18	3
9½	459 =	27	13	15	290 =	17	10
10	436 =	26	7	15½	281 =	17	
10½	415 =	25	2	16	272 =	16	8
11	396 =	24		16½	264 =	16	

For an area of one acre, 160 square rods; 5 by 32 rods will be good dimensions. This will make ten plots 32 by ½ rods=16 square rods.

Note here:

	Feet	=	Rods.	Feet.
Length of the whole area (and of each plot)	——	=	——	——
Width of the whole area	——	=	——	——
Width of each plot	——	=	——	——

THE REPORTS AND THEIR VALUE.

For reports of the results of experiments blanks were sent to the experimenters, which they were requested, if so inclined, to fill out and return. The blanks were sheets of paper about 12 by 19 inches, with space for noting on one side description of soil, subsoil, &c.; previous treatment, manuring, and yield; weather during experiment; fertilizers, and how applied; method of sowing, planting, tillage, &c.; and other details and remarks. The other side was devoted to details of

size of plots, dates of planting and harvesting, amounts, quality, and value of produce in grain. roots. tubers, stalks, &c., by pounds and bushels; calculated profit or loss, &c.

It has been a matter of surprise and gratification to me, not only that so many of the experimenters should have made reports, but that the reports should have been made so well. Some of those received are brief, most are well filled, and many entirely so, while several have additional interesting and suggestive statements covering a number of pages, for which there was not room on the blanks.

I have attempted herewith to reproduce, as faithfully as the printer's conditions will allow, one of these reports—that of an experiment with corn, by Mr. W. C. ATWOOD, of Watertown, Conn. Mr. Atwood's estimates of values of produce are much larger than would be proper in many places, but are doubtless quite correct for his season and region.

WHAT THE REPORTS SAY—FAILURES AND SUCCESSES.

Many of the reports have no decided story to tell, and some none at all, except failure everywhere. Some were on land so rich that the action of the fertilizers was obscured by the stores of plant food in the soil; others on soil seemingly in such physical condition that no artificial supply of plant food could make it fertile. The many vicissitudes to which farming is subject affected the growth in these, as in general cultivation. Crows, cows, cut-worms, grubs, and potato beetles worked the injury and ruin of many: frosts, heat, and drought that of many more. Oftentimes the failure seemed to be due to the improper conduct of the experiment. The fertilizers were often applied so close to the seed as to injure or destroy the crop; but the most serious difficulty of all, I think, has been found in the unevenness of the soil. Fields that seemed to be uniform, proved very variable. The plots on one side were sometimes drier than on the other; or one plot was on old sod ground and another had been lately cultivated, and showed the effects of previous manuring; while some were irregular for reasons upon which neither the experimenters nor the reports throw any light. Some of the trials were made in ways which, though meeting the author's wishes and eminently useful for their purpose, do not admit of tabulation. Some are defective in such ways as to impair or destroy their value.

The fact is, that these experiments are subject to all the natural vicissitudes of ordinary farming, and a good many others besides, that come from lack of care, experience, or understanding how to make them, or of patience in their execution.

But on the whole I may say that the general character of the work, as evidenced by the report, has seemed to me to indicate a surprising and most gratifying amount of intelligence, thoughtfulness, and scientific spirit. Indeed, there is here a most forcible illustration of the

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or cold, wet or dry, during each
—*Cold and wet, land could not be pl*
1st to 15th cold and quite wet ; rest
—*Good growing weather, favorable f*
—*First week hot and dry. Second coo*
t—*Excellent weather for developmen*
e whole what was the character o

lanted in drills 40 inches apart and applying some
f fertilizer along the drills so as to c ith the soil as
d injury to the seed. By passing ov enly scattered,
ked in carefully so as not to obscure h. Expecting
returns from some, I made the drill rtilizers well.

M

bout May 1, plowed the acre about 4 wo weeks later
again 6 inches deep, leaving sorrel each day, then
ing with light brush drag and laid ce (one for the
d one for intruders of various sorts, e hoe. Stakes
t and labels attached. Cultivated a

planted late owing to frost, which fo owed.
estimating the dry weight of fodder t., thus giving
antage to partially and wholly unm values I con-
to offset the better quality of grain i them another
advantage.
ad no expectation of a crop on such e or two more
ured plots.
sing a dressing of 40 cords of stable ng three times
eding once, the whole costing about nure has since
as follows : First year, 410 bushels uted at $1,144.

* With oth

DETAILS OF EXPERIMENTS.

Kind of crop: *Early Canada corn.* Set of fertilizers. "Acre set" or "Half-acre set," . Dimensions of each plot: Length, 330 *ft.*; width, 13 *ft.*; No. of square rods, 16. If in rows, distance apart, 40 *inches.* If in hills, distance from hill to hill, . Date of planting: *May 19th.* Date of harvesting: *Sept. 10th.*

PLEASE OBSERVE THE FOLLOWING DIRECTIONS.

COLUMN No. **1**.—As the bags are numbered **A, B, C, D,** &c., the plots can have the same numbers. After these can follow the other fertilizers used—lime, stable manure, &c., &c. The unmanured plots are designated by ciphers, **0, 00, 000**, and the places for them precede those for the manured plots. This makes the order of plots on this paper different from that in the field. Please state order of plots below.

COLUMNS Nos. **2** and **3**.—If the whole of the contents of one bag was applied to each plot, indicate the fact by check, in column **3**, thus: +; otherwise, state exact amount used on each plot.

COLUMNS Nos. **4** and **5**.—Designate merchantable produce as "good," that which is not merchantable as "poor" unless you have some better way of distinguishing between the qualities. In the latter case follow your own plan and explain it below. Give amounts per plot as determined by weighing, in column **4**, or by measurement, in **5**. It will be better, of course, to both weigh and measure. With corn, state whether measured in the ear or shelled. It will be very useful to determine weights of both ears and shelled corn, and shrinkage in curing.

COLUMN No. **6**.—It will be very interesting to learn the proportion of stalks or straw to grain under the influence of the different fertilizers: Be particular to have stalks well cured, if practicable, before weighing. State condition of dryness, *i. e.*, green or well dried.

COLUMNS Nos. **7**, **8**, and **9**.—In computing bushels from pounds, or pounds from bushels, or shelled corn from corn in the ear, be particular to make due allowance for quality of produce. 70 lbs. of well-cured corn in the ear may make a bushel of shelled corn, while, if the ears were weighed just after husking, it would take much more than 70 lbs. to make a bushel. So two bushels of good ears may make a bushel or more of shelled corn, while two bushels of "nubbins" would make only a fraction of a bushel. And a measured bushel of shelled corn may weigh 56 lbs., or it may weigh 60 lbs. The point is to get as near as possible to the true quantity, quality, and value of the crop. Give below your figures for pounds per bushel, &c., and other explanations of numbers and methods used in calculations.

COLUMNS Nos. **10** and **11**.—Calculate average yield of unmanured plots and substract from that of each unmanured plot.

COLUMNS Nos. **12** to **14**.—Compute, if convenient, giving your figures for cost of fertilizers and applying, and valuations of products below. The following figures for cost of fertilizers per acre will probably not be far out of the way: **A**, \$8.00; **B**, \$5.25; **C**, \$4.50; **D**, \$11.62½; **E**, \$10.87½; **F**, \$9.75; **G**, \$16.12½; **H**, \$1.00. Change those estimates if you choose, and tell why.

COLUMNS **10** to **14** are not necessary for this report, though they will be very interesting. Columns **1** to **9** are most important.

Pounds allowed for bushel of produce, *seventy pounds per bushel ears of corn for 56 lbs. shelled corn.* Average yield of unmanured plots, 60 *lbs. ears per plot, or about 8 bushels shelled corn per acre. I estimate at 75 lbs. ears, as my crop is about half cured. I estimate 3,000 lbs. of stalks per ton of dry fodder.*

1	2	3	4		5		6	7		8		9	10		11	12	13	14		
	FERTILIZERS.		YIELD PER PLOT.					CALCULATED YIELD PER ACRE.					INCREASE OF YIELD.			PECUNIARY RESULT.				
			Give pounds, bushels, or both.				Stalks or straw.	Please compute carefully and insert without fail either pounds, or bushels, or both.					Compute or not, at discretion.							
No. of plot.	Kind.	Amount per plot.	Grain, roots, or tubers. (If corn, state whether in ear or shelled.)					Grain, roots, or tubers. (If corn, give figures for shelled, not ears.)				Stalks or straw.	Grain, roots, or tubers, per acre.		Stalks, straw, &c., per acre, in pounds.	Value of increase, per acre, \$ cts.	Cost of fertilizers, freight, and applying, per acre.	Gain or loss per acre.	Appearance during growth.	Appearance and quality of produce.
			Pounds.		Bushels.			Pounds.		Bushels.			Bushels.							
		Pounds.	Good.	Poor.	Good.	Poor.	Pounds.	Good.	Poor.	Good.	Poor.	Pounds.	Good.	Poor.						
0	Nothing			60.0			169	600		8.0		1,690								
A	Nitrate of soda	20		111.5			211	1,115		14.65		2,110	6.65		420	0.37	7.50	—1.13		**000**, *Unsound nubbins.* **A**, " "
B	Superphosphate	30		176.0			289	1,760		23.3		2,890	15.30		1,200	15.24	5.25	9.99		**B**, *Better.*
C	Muriate of potash	20	221.0				34t	2,210		29.35		3,410	21.35		1,720	17.08	4.50	12.58		**C**, *Fair quality.*
D	Nitrate of soda Superphosphate	50	291.5				400	2,915		38.65		4,000	30.65		2,310	30.39	8.62	2t.68		**D.** *Much better, sound.*
00	Nothing																			
E	Nitrate of soda Muriate of potash	35	287.0				380	2,870		38.2		3,800	30.20		2,110	29.43	2.00	11.43	*July 10,* **G** *taking lead.* **F** *good color, hard after* **G**. **000** *not so good color.* **00** *much the same as* **H**. **O** *looks finely, close upon* **G**. *Barn-yard the best. Aug. 15, no great difference between* **O** *and* **G** *and barn-yard. Sept. 1st,* **G** *will ripen earliest,* **O** *next, while* **B Y** *will give the most foliage,* **000** *and* **H** *as well as* **H** *and lime will yield but little grain, and less though much better fodder.*	**E.** *Much better, sound.*
F	Dissolved bone-black Muriate of potash	50	302				412	3,020		40.2		4,120	32.20		2,430	3t.83	9.75	21.08		**F.** *Much better, sound.*
G	Nitrate of soda Superphosphate Muriate of potash	65	601.5				445	6,015		80.2		4,450	72.15		2,700	04.60	17.25	46.35		**G**, *Excellent grain.*
H	Plaster	20																		**H**, *Unripe and poor.*
K	(1)			81			220	810		10.6		2,200	2.00		510	4.47	0.80	2.25		**K**, *Sound, ripe, and good.*
L	(2)		676.0				350	6,760		90.0		3,500	82.00		1,810	70.12	30.00	40.12		**L**, *Sound, ripe, but small.*
M	*Lime* (3)		219.0				278	2,190		29.2		2,780	21.10		1,090	19.04	8.00	11.64		**M.** *Unripe and poor.*
N		50		90			217	900		12.0		2,170	4.00		480	4.40	0.50	3.96		**N.** *Very good and sound.*
O	*Manure* (4)	1½ *cords.*	30.0				400	4,300		57.3		4,000	49.25		2,310	45.17	3.00	42.17		**O.** *Best of all.*
000	*Nothing*		680.0				450	6,800		90.5		4,500	82.50		2,810	73.02	75.00	—1.98		

(1.) *Compost: Night-soil, hen manure, and plaster; handful in hill.* (2.) *Wood ashes ½ handful in each hill.* (3.) *Wood ashes and plaster, spoonful in hill at planting and some between first and second hoeings.* (4.) *Barn-yard manure, 15 cords per acre.* (5.) **D, E, F,** *and* **G**, *were mixtures of* **A, B,** *and* **C**, *except that they had only 15 lbs. of nitrate of soda.*

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ts from bushels, or shelled corn from corn in the ear, be particular to make due
ar may make a bushel of shelled corn, while, if the ears were weighed just after
two bushels of good ears may make a bushel or more of shelled corn, while two
a measured bushel of shelled corn may weigh 56 lbs., or it may weigh 60 lbs. The
lue of the crop. Give below your figures for pounds per bushel, &c., and other

nd substract from that of each unmanured plot.
cost of fertilizers and applying, and valuations of products below. The follow-
of the way: **A**, $8.00; **B**, $5.25; **C**, $4.50; **D**, $11.62½; **E**, $10.87½; **F**, $9.75; **G**,

ry interesting. Columns **1** to **9** are most important.

is about half cured. I estimate 3,000 *lbs. of stalks per ton of dry fodder.*

Appearance during growth.

Appearance and quality of produce.

taking lead. **F** *good color, hard after* **G**.
so good color. **OO** *much the same as* **H**. **O**
ely, close upon **G**. *Barn-yard the best. Aug.*
reat difference between **O** *and* **G** *and barn-*
Sept. 1st, **G** *will ripen earliest,* **O** *next, while*
ll give the most foliage, **OOO** *and* **H** *as well as*
ime will yield but little grain, and less though
ter fodder.

OOO. *Unsound nubbins.*
A. " "
B. *Better.*
C. *Fair quality.*
D. *Much better, sound.*
E. *Much better, sound.*
F. *Much better, sound.*
G. *Excellent grain.*
H. *Unripe and poor.*
K. *Sound, ripe, and good.*
L. *Sound, ripe, but small.*
M. *Unripe and poor.*
N. *Very good and sound.*
O. *Best of all.*

ords per acre. (5.) **D**. **E**. **F**, *and* **G**, *were mixtures of* **A**. **B**. *and* **C**, *except that*

truth that among our farmers there is an amount of intelligence and ability which is not appreciated either by themselves or by the community at large, but which is capable of making, indeed is making, a very rapid advance in the intellectual character of our agriculture.

The main results of the general experiments are set forth in Tables IV to XI of the appendix. In lack of place for giving all of the details of the reports, an attempt is made to tabulate some of the principal data with the figures for produce.

TABULAR STATEMENTS OF RESULTS OF THE EXPERIMENTS.

Concerning the arrangement of these tables, the following remarks may be made:

1. The figures given by the experimenters are complete in all cases except a very few, in which minor mistakes were apparent.

2. In some cases the materials were applied in areas different from those recommended. The variations thus made in the amounts per acre, though considerable in some cases, do not affect the general result, when all are averaged together.

3. The estimates for pounds per bushel of corn and potatoes vary considerably. Corn was generally weighed in the ear, and the shelled corn computed, the different experimenters allowing from 70 to 80 pounds of ears for one bushel of shelled corn. Where the ears were measured, 2 bushels are generally reckoned equal to 1 of shelled corn. I am inclined to think that generally too little allowance was made for the shrinkage that comes in curing. It is evident that the poorer yields appear to an unfair advantage in this way, unless the different qualities of produce are sorted. With corn, for instance, the small yields—those on the unmanured plots and with inefficient fertilizers—would have much larger proportions of poor corn than the good yields. A bushel, or 75 pounds of poor ears, would give less shelled corn than the same amount of good corn. The small errors thus introduced in the tables appear to the advantage of the poorer fertilizers in the comparison.

I suppose that but few of the gentlemen whose reports are before me are used to accurate experimenting, and there are doubtless many sources of error in their work which experience in methods of accurate research and more adequate appliances would have eliminated. Several in particular occur to me. One, as above said, is that the statements of results of weighings and measurements often fail to make due allowance for the quality of the crop. Another is the lack, in the majority of the cases, of unmanured spaces between the plots to prevent the roots of one from feeding upon the fertilizers of the other. Another is the unevenness of the soil, and a fourth, improper application of the fertilizers.

For that matter, I can see many imperfections in this method of experimenting. But if we work in the right spirit, experience will be our best teacher, and our errors our most effective lessons. Indeed it seems

to me that these trials are only the beginning of what may be developed into work of the greatest value.

GENERAL AVERAGES OF EXPERIMENTS.

The following tables will be interesting—the former giving averages of results, the latter giving results of experiments which were repeated from year to year :

Averages of results of experiments of 1878, 1879, 1880, *and* 1881.

Products.	Kinds and amounts of fertilizing materials applied per acre.	O	A	B	C	D	E	F	G	H	
		No manure.	Nitrate of soda, 200 pounds.	Dissolved bone-black, 300 pounds.	Muriate of potash, 200 pounds.	Nitrate of soda, 150 pounds. Dissolved bone-black, 300 pounds.	Nitrate of soda, 150 pounds. Muriate of potash, 200 pounds.	Dissolved bone-black, 300 pounds. Muriate of potash, 200 pounds.	Nitrate of soda, 150 pounds. Dissolved bone-black, 300 pounds. Muriate of potash, 200 pounds.	Plaster, 200 pounds.	Farm manures.
	AVERAGE PRODUCE PER ACRE.	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*
Corn	27 experiments in 1878	24.6	30.4	33.5	33.3	39.1	39.6	42.9	48.6	28.9	45.9
	26 experiments in 1879	24.0	30.3	36.9	33.2	38.6	34.7	40.1	46.7	29.1	43.2
	20 experiments in 1880	32.1	35.2	43.2	37.1	46.8	40.3	47.5	48.1	39.8	16.6
	7 experiments in 1881	24.2	28.8	28.7	30.3	33.5	29.2	35.3	37.1	....	......
	80 experiments in 1878–'81	26.2	31.4	36.6	34.0	40.3	37.2	42.5	46.8	....	......
Potatoes	9 experiments in 1878	100.0	103.0	123.4	129.6	143.2	106.0	153.4	177.3	106.0	132.9
	9 experiments in 1879	58.2	76.4	90.7	86.5	96.3	84.7	123.0	143.6	69.3	131.6
	4 experiments in 1880	76.3	83.3	98.2	86.7	105.8	99.4	125.0	135.3	97.9	101.3
	3 experiments in 1881	28.2	44.2	43.7	39.7	54.4	41.9	59.5	87.7	....	......
	25 experiments in 1878–'81	72.5	83.2	98.0	96.4	109.6	89.6	130.8	147.7	....	......
	Average of the experiments of 1878, 1879, and 1880, in which farm manures were used:										
	Corn, 43 experiments:										
	Average produce	24.8	30.2	34.9	38.0	40.6	25.1	41.8	47.7	26.3	45.3
	Average increase	....	5.4	10.1	13.2	15.8	.3	17.0	22.9	1.5	20.5
	Potatoes, 15 experiments:										
	Average produce	72.1	80.2	95.0	103.3	112.4	87.7	128.9	154.6	84.1	130.1
	Average increase	....	8.1	22.9	31.2	40.3	15.6	56.8	82.5	12.0	58.0
Sweet potatoes	5 experiments	71.2	133.9	102.3	164.3	124.5	195.2	164.9	214.2	(60.0)	272.7
Turnips	3 experiments	....	425.0	416.7	387.7	477.0	454.0	489.7	601.0	412.0	440.0
Sugar beets	1 experiment	795	1,013	1,174	851	1,116	988	1,091	1,119.0	961	......
Onions	1 experiment	290	530	510	680	620	500	650	610	400	390
Oats	4 experiments	21.6	25.0	36.1	22.6	47.7	38.1	30.2	41.5	....	......
Cotton	1 experiment	587	865	1,162	564	1,599	932	1,219	1,541	....	......
Clover	1 experiment	480	700	1,200	940	1,080	560	1,140	1,200	....	......

Averages of results of experiments, &c.—Continued.

Products.	Kinds and amounts of fertilizing materials applied per acre.	O	A	B	C	D	E	F	G	H	
		No manure.	Nitrate of soda. 200 pounds.	Dissolved bone-black, 300 pounds.	Muriate of potash, 200 pounds.	Nitrate of soda, 150 pounds. Dissolved bone-black. 300 pounds.	Nitrate of soda. 150 pounds. Muriate of potash. 200 pounds.	Dissolved bone-black. 300 pounds. Muriate of potash. 200 pounds.	Nitrate of soda. 150 pounds. Dissolved bone-black. 300 pounds. Muriate of potash. 200 pounds.	Plaster. 200 pounds.	Farm manures.
	AVERAGE INCREASE PER ACRE.										
Corn	80 experiments	....	5.2	10.4	7.8	14.1	11.0	16.3	20.6	....	......
Potatoes	25 experiments	....	9.3	25.5	23.9	37.1	17.1	58.3	75.2	....	......
Oats	4 experiments	....	3.4	11.5	1.0	26.1	16.5	8.6	19.9	....	......
Sweet potatoes	5 experiments	....	59.4	27.8	89.8	50.0	120.7	90.2	139.7	—14.5	198.2
Turnips	3 experiments	....	220.4	212.1	183.1	273.4	249.4	285.1	396.4	207.4	235.4
Sugar beets	1 experiment	....	218	379	56	321	193	294	323	164	......
Onions	1 experiment	....	240	220	390	330	210	360	320	110	100
Cotton	1 experiment	....	278	575	23	1,012	345	632	951	....	......
Clover	1 experiment	....	220	720	460	600	80	660	720	....	......

Repetitions of experiments, 1878, 1879, 1880, *and* 1881.

Names.	Number of plot.			O.	A.	B.	C.	D.	E.	F.	G.	H.	
	Fertilizing materials.			No manure.	Nitrate of soda.	Superphosphate.	Muriate of potash.	Nitrate of soda. Superphosphate.	Nitrate of soda. Muriate of potash.	Superphosphate. Muriate of potash.	Nitrate of soda. Superphosphate. Muriate of potash.	Plaster.	Farm manure.
Prof. J. R. Farrington	Corn repeated on same plots in 1879.	1878,	Corn .... bushels.	20.3	19.3	29.1	32.9	37.0	42.9	39.0	39.8	......	34.8
Prof. W. H. Jordan	Three crops of 1878 side by side in one experiment. In 1879 experiment repeated with potatoes, same fertilizers on same plots.	1878,	Beans ..... pounds	540.0	660.0	630.0	765.0	690.0	990.0	600.0	750.0	540.0	810.0
			Corn ..... bushels	38.5	44.5	42.0	63.0	62.0	69.0	42.5	58.0	40.0	68.5
			Rutabaga ... bushels	225.0	285.0	315.0	240.0	428.0	203.0	413.0	518.0	263.0	300.0
		1879,	Potatoes ... bushels	37.0	49.0	38.0	73.0	47.0	59.0	111.0	129.0	35.0	116.0
Prof. W. H. Jordan	Experiment of 1880, on land contiguous to that of previous ones.	1880,	Corn .... bushels	9.6	9.8	21.1	14.1	30.0	13.0	20.0	16.5	.....	.....
W. I. Bartholomew, Connecticut	Experiments of 1878, on different parts of same field. Experiments of 1879, side by side on land adjoining corn experiments of 1878.	1878,	Corn .... bushels	17.7	18.7	39.9	19.1	41.9	21.1	43.1	51.7	......	49.8
		1878,	Potatoes .. bushels	130.0	162.0	200.0	125.0	210.0	......	220.0	250.0	150.0	......
		1879,	Corn .... bushels	7.7	7.4	36.5	7.7	41.4	7.1	42.0	15.7	......	36.0
			Potatoes .... bushels	38.0	32.0	62.0	33.0	96.0	42.0	98.0	109.0	......	36.0
	Experiments of 1880, 1881.	1880,	Corn .... bushels.	30.	20.1	43.2	24.7	45.1	24.0	52.8	50.0	......	......
	Continuation of those of 1879 with same fertilizers, and crops on same plots.		Potatoes .... bushels.	70.	90.0	112.0	116.0	132.0	106.0	102.0	152.0	......	......
		1881,	Corn ... bushels.	9.9	5.8	12.4	10.0	16.7	5.5	25.2	28.8	......	......
			Potatoes .. bushels.	44.0	48.9	58.0	50.0	58.0	52.0	74.0	100.0	......	......
Dr. H. A. Cutting, Vermont	Same fertilizers on same plots both seasons.	1878,	Potatoes .. bushels.	30.0	40.0	80.0	20.0	100.0	60.0	100.0	140.0	60.0	80.0
		1879,	Oats ... bushels	15.6	15.3	45.6	10.0	58.7	54.4	28.1	40.0	27.8	26.9
S. H. Rising, Vermont	Same fertilizers on same plots both seasons.	1878,	Corn .... bushels	27.5	51.9	40.0	49.1	47.1	52.4	47.7	51.7	40.0	52.6
		1879,	Potatoes .... bushels	80.0	105.0	110.0	175.0	94.0	125.0	80.0	145.0	90.0	120.0
C. Sage, Connecticut	Contiguous fields of same farm, similar soil.	1878,	Corn .... bushels	11.3	21.5	16.5	62.3	11.2	68.9	70.3	84.0	......	43.8
		1879,	Corn .... bushels.	42.0	49.2	46.0	59.0	41.1	58.0	63.4	60.8	......	
J. J. Dearing Georgia	Different fields	1878,	Corn .... bushels	5.5	7.5	10.7	7.8	18.4	.....	14.5	18.5	9.4	...
		1878,	Cotton ...... pounds.	104.5	38.5	242.0	66.0	599.5	.....	457.0	693.0	41.0	...
		1879,	Cotton ...... pounds	......	......	......	......	1,204.0	819.0	1,035.0	1,023.0	..	
C. Miller & Son, Vermont	Different fields	1878,	Corn .... bushels.	20.2	40.5	57.2	30.0	67.9	......	71.0	70.5	23.0	60.0
		1879,	Corn .... bushels	21.9	27.5	33.7	23.7	30.0	31.2	28.7	38.7	31.7	......
Edward Hicks, Long Island	Different fields	1878,	Corn .... bushels	49.2	60.0	54.0	37.8	54.3	......	57.3	76.0	48.3	66.8
		1879,	Corn .... bushels.	32.5	53.3	54.5	59.6	69.6	82.2	76.5	82.7	58.7	55.3
		1880,	Corn .... bushels.	54.3	50.3	60.4	67.8	60.3	72.0	76.0	70.0	......	......
		1881,	Corn .... bushels.	16.3	26.0	22.8	34.5	24.3	29.5	28.2	28.7	......	......

Repititions of experiments, &c.—Continued.

Names.	Number of plot			O.	A.	B.	C.	D.	E.	F.	G.	H.	.
	Fertilizing materials			No manure.	Nitrate of soda.	Superphosphate.	Muriate of potash.	Nitrate of soda. Superphosphate.	Nitrate of soda. Muriate of potash.	Superphosphate. Muriate of potash.	Nitrate of soda. Superphosphate. Muriate of potash.	Plaster.	Farm manure.
Buel Landon, Veemont	Different fields	1878,	Corn .... bushels	7.0	17.5	10.3	9.2	16.5	15.0	18.6	13.5	14.4	48.6
		1879,	Corn .... bushels.	19.7	24.2	22.3	11.0	31.3	27.2	14.0	33.4	25.8	18.0
J. M. Manning, Massachusetts	Same fertilizers on same plots both seasons.	1879.	....	11.3	11.2	16.6	11.0	18.9	10.0	13.3	15.9	4.5	23.9
		1880,	....	19.7	25.5	19.2	29.1	30.4	24.5	26.9	43.2	14.3	53.7
		1881,	Clover ...... pounds.	480.0	700.0	1,200.0	940.0	1,080.0	560.0	1,140.0	1,200.0	......	......
J. W. Pierce, Massachusetts*	Same fertilizers on same plots both seasons.	1879,	Corn .... bushels.	3.3	2.7	12.0	6.7	12.0	5.5	13.7	13.7	3.5	39.7
		1880,	Corn .... bushels.	29.6	27.1	34.0	25.4	38.3	......	44.8	44.8	26.7	......

* Except that the experiment of 1880 covered only about one-half of the area of 1879, the rest being on new ground.

NOTES UPON INDIVIDUAL EXPERIMENTS.

Having thus given a general outline, and more or less specific statement of the experiments in general, it will be proper now to speak of some of the details. It is a matter of regret that so much of faithful, excellent, and useful work must be expressed in so little space. Almost every report contains material worthy of especial mention; and many of the experimenters have so carried out their trials as to give them no little scientific value. To select a few for especial discussion seems injustice to others likewise worthy. I am compelled to restrict the particular discussion of individual experiments, however, to a small number; and in so doing, other things being equal, I choose the work of practical farmers, rather than that of agricultural colleges, because the latter usually find publication in detail elsewhere; and in the belief that one of the most useful features of these experiments is the bringing out of the talent of individual men and the showing of what ordinary farmers can do?

MR. BARTHOLEMEW'S EXPERIMENTS.

The experiments of Mr. Bartholemew were begun in the year 1877, and have now been going on for five successive years; have covered nearly one hundred plots; been repeated on the same plots and with the same fertilizers and the same crops year after year, and on other parts of the same and contiguous fields with other crops, and are decidedly the most instructive and valuable ever made to my knowledge by a private individual in this country. They include:

(1.) An experiment with corn, begun in 1877 and continued through five years, with the same fertilizers and the same plots.

(2.) An experiment with potatoes, made in 1878. (See Appendix, Table V, No. 27.)

(3.) A special nitrogen experiment with corn in 1878. (Appendix, Table II, No. 13.)

(4.) A special nitrogen experiment with corn and potatoes, side by side (Appendix, Table I, No. 13), begun in 1879 and continued until the present.

(5.) A number of other trials not reported here.

I will first refer to Mr. Bartholomew's experiments with corn, which were begun in the year 1877, and continued on the same plots until the present time.

The plots were of ten square rods each. The soil is described by Mr. Bartholemew as "hill-land, a dark loam, moist, with clayey subsoil." The field was, in 1874, an old meadow, yielding about one ton of hay per acre. In 1875 it was plowed, dressed, and planted with corn, and yielded 35 bushels per acre. In 1876 it was sowed to oats, with no additional manure, the yield being 40 bushels per acre. In 1877 experiments began with corn. The land had thus been out of grass for

three years previous to the beginning of the experiment, or, up to the present time, eight years. The seasons of 1877 and 1878 were on the whole favorable. In 1879 "the spring was late. There were some storms in July and August which beat the corn nearly flat and stripped the leaves into shreds. Frost killed the corn September 25 before it matured." In 1880 the season was hardly unfavorable; in 1881 very unfavorable to the growth of corn.

The fertilizing materials used were as follows:

No. of plot.	Fertilizers. Kind.	Pounds per acre.	At price per ton.	Cost per acre.	Furnishing valuable ingredients. Kind.	Assumed per cent.	Pounds per acre.	Cost per acre.
1	Dried blood	320	$40 00	$6 40	Nitrogen	10	32	$6 40
2	Dissolved bone-black	320	35 00	5 60	Phosphoric acid	16	51	5 60
3	Muriate of potash	320	45 00	7 20	Potash	50	160	7 20
4	Dried blood	160	37 50	6 00	Nitrogen	5	16	3 20
	Dissolved bone-black	160			Phosphoric acid	8	25½	2 85
5	Dried blood	106⅔	40 00	6 40	Nitrogen	3. 3	10⅔	2 13
	Dissolved bone-black	106⅔			Phosphoric acid	5. 3	17	1 87
	Muriate of potash	106⅔			Potash	16. 7	53⅓	2 40
6	Plaster	320	10 00	1 60				

Wood ashes, dry and leached, and farm manures were likewise employed, as indicated below. A number of brands of manufactured fertilizers were also tried, with results according with those from the regular experimental fertilizers.

Plot.	Fertilizer. Kind.	Amount per acre.	Yield of shelled corn per acre in bushels. 1877.	1878.	1879.	1880.	1881.
1	Dried blood	320 pounds	13. 7	10. 0	*	21. 2	*
2	Superphosphate	320 pounds	41. 6	39. 8	21. 7	39. 3	12. 8
3	Muriate of potash	320 pounds	15. 5	11. 0	*	17. 5	*
4	Mixture I and II	160 pounds of each	38. 0	35. 4	22. 4	37. 0	11. 3
5	Mixture I and II and III	106⅔ pounds of each	33. 5	30. 5	20. 7	33. 3	8. 7
6	Plaster	320 pounds	19. 4	11. 0	*	15. 0	*
0	No manure		6. 2	3. 0	*	13. 5	*
7	Wood ashes, dry	32 bushels	34. 9	30. 4	*	38. 8†	†
8	Wood ashes, leached	48 bushels	37. 7	36. 6	24. 6†	37. 7‡	‡
9	Hog manure	16 cart loads	41. 1	46. 6		37. 7	15. 1
10	Hen manure	20 bushels	54. 9	56. 7			

* Entire failure.

† Dissolved bone-black, 480 pounds per acre, instead of ashes in 1880. Nothing in 1881.

‡ Ammoniated superphosphate, 480 pounds per acre, in place of ashes in 1880. Nothing in 1881.

In speaking of the results in 1881, Mr. Bartholemew says:

The land on which these experiments have now been conducted for five successive years was also plowed the two previous years, making seven years in succession under cultivation. The soil has become very light, has washed considerably on to the adjoining meadow, and seems to have become unfitted for corn. The plot fertilized with a good cart load of farm manure has produced but little more than that with phosphate. I think the condition of the soil has become such that but little more can be learned from the effect of fertilizers upon it.

Two things are especially worthy of mention in connection with this experiment. (1.) That wherever phosphoric acid was supplied a notable increase of yield resulted, and that without the addition of phosphoric acid there was no increase of crop. Indeed, the following statements from the report of the experiments in 1877 are, with few exceptions, as necessarily with variations of season almost equally appropriate to those of each of the following years. The ashes were not analyzed. The statements regarding them are made on the very probable assumption that the composition was as ordinarily found.

(1.) In the four cases, Nos. 1, 3, 6, and 0, where phosphoric acid was not supplied, the crop failed. (2.) In every case where phosphoric acid was supplied, either alone (*i. e.*, as superphosphate with the lime and sulphuric acid incident thereto) or with other materials in Nos. 2, 4, 5, 8, 9, and 10 the crop was good. (3.) The amounts of phosphoric acid per acre in Nos. 2, 4, and 5 were 51, 25½, and 17 pounds, respectively; the yields, 41.6, 38, and 33.5 bushels, showing a corresponding decrease. Comparisons of the amounts of phosphoric acid applied and corn produced in the other cases, of which limited space excludes details, show a similar and singularly uniform ratio between the two. This parallelism between phosphoric acid and yield runs through the plots with ashes, which contain less of the phosphoric acid, and brought less corn, and those with farm manures, which contain more and brought more. (4.) The produce with potash salt and with dried blood alone was less than on the one plot with no manure. (5.) While the crop responded uniformly to the phosphoric acid, it got little apparent benefit from the other ingredients of either the chemical fertilizers, the ashes, or the farm manure.

The main feature of the story of the first year is that of the fifth; without phosphoric acid, failure; with it, a larger or smaller yield, as more or less is used, and very little help from potash or nitrogen. But there is this addition, that phosphoric acid alone is unable to carry the crop year after year.

Another point worthy of mention is that the land has refused to produce corn in good quantities for a number of years in succession with any of the fertilizers used. This is worthy of record, especially in view of the fact that on another part of the same field corn and potatoes are being cultivated continuously with different fertilizers.

Mr. Bartholemew's special nitrogen experiment of 1878, detailed in Table I of Appendix, and experiments with potatoes in the same year, given in Table V of the Appendix, were made on a contiguous part of the same field as the ones just described. As regards the effects of phosphoric acid, potash, and nitrogen, they coincided fully with the experiment just described.

In these experiments, then, potatoes had responded to phosphoric acid, potash, and nitrogen, though phosphoric acid was by far the most effective ingredient. The corn had responded very decidedly to the phosphoric acid, and had paid but little heed to the other ingredients. Two inferences seem to be deducible from these results; first, that the soil was especially deficient in phosphoric acid; second, that corn and potatoes differ materially in the effects of the several fertilizing ingre-

dients upon their growth. The soil experimented upon seemed to be reasonably uniform; still Mr. Bartholemew felt it desirable to test the uniformity more thoroughly.

He accordingly planned an experiment in which corn and potatoes should be planted side by side, and in which intervening plots should be left between the experimental plots proper; that is, plots of one-tenth of an acre each were laid out and received the experimental fertilizers. Each one of these was divided lengthwise and half devoted to corn and the other half to potatoes. Between each two experimental plots was an intervening plot. All of the plots were treated uniformly, and thus gave a measure of the uniformity of the soil. The experiment has now been going on for three years. The table herewith is a transcript of Mr. Bartholemew's report of the results in 1881. A little study of the figures will show how uniformly the conclusions above mentioned are borne out by the whole five years' work.

Special nitrogen experiment with corn and potatoes, 1881.

By W. I. Bartholemew, *Putnam, Conn.*

No. of plot.	Kind of fertilizers.	Amount per plot.	Experimental plots. Potatoes. Good.	Experimental plots. Potatoes. Poor.	Experimental plots. Corn, ears. Good.	Experimental plots. Corn, ears. Poor.	Intervening plots. Potatoes. Good.	Intervening plots. Potatoes. Poor.	Experimental plots. Potatoes. Good.	Experimental plots. Potatoes. Poor.	Experimental plots. Corn, shelled. Good.	Experimental plots. Corn, shelled. Poor.	Intervening plots. Potatoes. Good.	Intervening plots. Potatoes. Poor.	Increase over no manure. Potatoes. Total.	Increase over no manure. Corn. Total.	Increase over no manure. Potatoes. Total.	Value of increase per acre. Potatoes.	Value of increase per acre. Corn.	Cost of fertilizers, freight, and applying per acre.	Gain or loss per acre. Potatoes.	Gain or loss per acre. Corn.
		Lbs.	*Bu.*	*Bu.*	*Lbs.*	*Lbs.*	*Bu.*	*Bu.*	*u.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*					
1	....	7½	1.3	1.1	10	30	4.8	1.2	26	22	2.5	6.0	96	24	4	0.5	74	$3 00	$0 35	$6 00	*$3 00	*$5 65
2	Superphosphate	15	1.7	1.2	32	22	4.4	1.5	34	24	8.0	4.4	88	30	12	4.4	66	9 00	3 08	6 00	3 00	*2 92
3	Muriate of potash	7½	1.2	1.3	20	25	4.3	1.1	24	26	5.0	5.0	86	22	2	2.0	64	1 50	1 40	3 00	*1 50	*1 60
0	Nothing	0	.8	1.4	7	28	--	....	16	28	1.7	5.6	....	....	......	......	.....	......	......	.....	......	......
4	Nitrogen mixture Superphosphate	7½ 7½	1.6	1.3	38	36	4.3	1.1	32	26	9.5	7.2	86	22	10	*8.7	64	7 50	6 09	12 00	*4 50	*5 90
5	Nitrogen mixture Muriate potash	7½ 15	1.3	1.3	6	20	4.4	1.2	26	26	1.5	4.0	88	24	4	2.5	66	3 00	1 75	9 00	*6 00	10 75
6	Superphosphate Muriate potash } Mixed minerals	15 7½	2.7	1.0	69	40	4.4	1.2	54	20	17.2	8.0	88	24	32	17.2	66	24 00	12 04	9 00	15 00	3 04
7	Mixed minerals, as No. 6 Nitrate of soda, ⅓ ration	22½ 7½	3.8	1.2	84	39	4.5	1.1	76	24	21.0	7.8	90	22	54	20.8	68	40 50	14 56	*15 00	25 50	44
8	Mixed minerals Nitrate of soda, ⅔ ration	22½ 15	3.3	1.5	49	52	4.7	1.0	66	30	12.2	10.4	94	20	44	14.6	72	33 00	10 22	21 00	12 00	10 78
9	Mixed minerals Nitrate of soda, full ration	22½ 22½	3.2	1.3	32	53	4.4	1.2	64	26	8.0	10.8	88	24	42	10.8	66	31 50	7 56	27 00	4 50	20 44
00	No manure	0	1.4	1.6	†21	†36	....	..	28	32	†5.2	†7.2	....	....	......	......	.....	......	......	.....	......	......
10	Mixed minerals.. Nitrogen mixture } ⅓ ration	22½ 7½	4.2	1.5	96	35	5.0	1.5	84	30	24.0	7.0	100	30	62	23.0	78	46 50	16 10	15 00	31 50	1 10
11	Mixed minerals.. Nitrogen mixture } ⅔ ration	22½ 15	4.1	1.3	100	32	5.0	1.2	82	26	25.0	6.4	100	24	60	23.4	78	45 00	16 38	21 00	24 00	*4 62
12	Mixed minerals.. Nitrogen mixture } Full ration	22½ 22½	4.6	1.1	102	28	4.8	1.0	92	22	25.5	5.6	96	20	70	23.1	74	52 50	16 07	27 00	25 50	*10 93
13	Mixed minerals Sulphate of ammonia	22½ 7½	3.9	1.2	72	32	4.4	1.0	78	24	18.0	6.4	88	20	56	16.4	66	42 00	11 48	15 00	27 00	3 52
14	Mixed minerals Dried blood, ⅔ ration	22½ 15	4.3	1.2	112	28	4.1	1.2	86	24	28.0	5.6	82	24	64	25.6	60	48 00	17 92	21 00	27 00	*3 08
	Peruvian guano Muriate of potash	22½ 7½	3.8	1.3	96	30	4.4	1.0	76	26	24.0	6.0	88	20	54	22.0	66	40 50	15 40	27 00	13 50	11 60
6	Mixed minerals, as No. 6	22½	3.1	1 4	104	29	4.3	1.5	62	28	26.0	5.8	86	30	40	23.8	64	30 00	16 66	9 00	21 50	6 34

The plots were $\frac{1}{20}$ acre each. The average yield of the unmanured plots is taken at 8 bushels of corn and 22 bushels of "good" potatoes, which is lower than the figures would bring, but allowance was made for extra yield of 00, which had evidently received some of the fertilizers from adjacent plots. The average increase of the intermediate plots of potatoes was 68 bushels. For details of experiment see Appendix C, 1881.

* Loss. † Gain.

In all the scores of trials which Mr. Bartholemew has made, the same results have been obtained. Corn responded largely to phosphoric acid, less to nitrogen, and scarcely at all to potash; and potatoes responded to all, but chiefly to potash. It should be added, however, that Mr. Bartholemew has oftentimes got the best results by using farm manures, supplemented by superphosphates. Indeed, in his case, as in many others, the proper use of manures for fertilizers is to supplement the manures of the farm.

MR. FAIRCHILD'S EXPERIMENTS.

The experiment of Mr. Fairchild, in 1881, was given in detail above. Others may be found in Tables I and II of the Appendix. In his experiments, which have been going on now for five years, Mr. Fairchild has been seeking the solution of a number of problems, some of which may be expressed thus:

(1) Do crops on my land demand more nitrogen, phosphoric acid, potash, sulphuric acid or lime, than my soil supplies?

(2) Do different plants differ with respect to their capacities for gathering these materials for themselves, and their consequent demand for them in fertilizers?

(3) In what forms, quantities, proportions, and ways, can I use these fertilizing elements with profit?

Five years ago Mr. Fairchild began a series of experiments somewhat on the plan of the general experiments already described. The results indicated that phosphoric acid would be especially efficient, though potash and nitrogen were likewise useful. Not content, however, with this, he went into some more elaborate trials, and finally undertook some series of special nitrogen experiments, as have been detailed. Being led to this by the facts that while nitrogen seemed very beneficial, yet it was very expensive, and hence it became a matter important to him to learn how much or how little could be used with profit, in the spring of 1880 he selected a portion of an old pasture, the soil of which was very poor, and seemingly of little value. On this he laid out twenty-five plots of one-twentieth of an acre each, and applied fertilizers to obtain corn, as shown in Table I of Appendix. In 1881 he repeated the experiment, putting the same fertilizers on the same plots, but divided the experimental area in two equal parts, by a line running across the experimental strips; devoting one-half to oats and the other to potatoes. The results of this experiment are set forth in Table I of the Appendix, and in more detail as above, in the chapter on the nitrogen experiments. In the fall of 1881 the land was sown to wheat and grass, and fertilizers applied as before. After taking off the wheat of 1882, Mr. Fairchild proposes to let the land lie in grass as long as it can be made to yield well. Thus, by using the same fertilizers on the same plots year after year, through the regular rotation, Mr. Fairchild is gaining definite information as to the effect, cost, and profit of the more

expensive ingredients of the fertilizers used, particularly of the nitrogen.

Some time since Mr. Fairchild favored me with a visit at my study, and gave quite a number of details concerning the results of his experiments and experience. With his permission I made notes of some of the conversation, and on looking them over after his departure, took occasion to send him a few further questions in a letter which he has kindly answered. The observations seemed to me so correct, apposite, and valuable that I asked the privilege of putting them in print. The argument, strongly urged, that they would be very useful to his fellow farmers, finally overcame the objections which his modesty interposed. I quote as nearly as practicable his own words in the statements which follow:

* * * On the whole, phosphoric acid in superphosphate and bone, and potash in muriate, have thus far proved most efficient. At the same time, in many cases at least, I like some nitrogen also, and think a complete fertilizer is the most profitable for me.

* * * As to the outcome of my experiments with nitrogen, that depends upon soil and crops. * * * In my experience thus far, nitrogen in small quantities has generally proved profitable. Bone and potash give a moderate yield of corn and oats on very poor land, but I like a good handsome crop, and 24 pounds of nitrogen added, has more than repaid the cost in increased yield of corn and oats. That is, mixtures containing "one-third ration" of nitrogen have been uniformly more profitable than "mixed minerals" alone, or than mixed minerals with a two-thirds or a full ration of nitrogen; and this is my experience on a larger scale. * * *

Yet in a number of cases potash salts with bone, and also with superphosphate, bring excellent crops without nitrogen, and the addition of nitrogen would be unprofitable.

My neighbor, Mr. Williams, had a very fine piece of corn this year, with only 200 pounds per acre of bone dust, and 150 pounds of muriate of potash, the two costing $7 per acre. I have noted quite a number of similar cases in this district. But my land was very badly run out when I took hold of it, and seemed to demand a little nitrogen. So far as I have observed, soils that have been well manured, seeded down, kept in grass awhile, and then plowed again, do well with potash and phosphoric acid, without artificial supply of nitrogen. My corn in last year's nitrogen experiments, rose with the amount of nitrogen added, but the increase was not enough to pay the cost of the 72 pounds or even of 48 pounds, though it did pay for the 24 pounds. And with the oats on the same plots the past season the yield rose with increase of nitrogen, but the smallest quantity was the most profitable, as you can see by comparing Plot No. 7 with Nos. 8 and 9, and No. 10 with 11 and 12.

But the potatoes gave a better response to the nitrogen than the oats. With them the two-third's ration, 48 pounds per acre, was the most profitable, and the value of the increase exceeds the cost of the fertilizer. With 48 pounds of nitrogen, the gain was $57 to $65, while with either 72 pounds or 24 pounds it runs from $40 to $59. I notice also, as a result of my experiments, that the potatoes seem to respond to the potash much more readily than either oats or corn.

To my question, "Have you arrived at any formulas as most suitable for fertilizers for your crops?" Mr. Fairchild answered as follows:

Yes and no. That is, I have made up my mind what will probably do well on my land and under my conditions for some of my crops. But I cannot say what would be most advantageous elsewhere, nor do I yet know exactly what will prove best for me years hence, or with crops I have not tested. For my corn I expect to use next spring 250 pounds of fine ground bone, 150 pounds muriate of potash (containing 50

per cent. actual potash), and 24 pounds of nitrogen in the cheapest form I can get it. So far as my experiments go, they indicate that sulphate of ammonia and nitrate of soda do rather better than dried blood. Nitrate of soda is cheap now, and I rather expect to use that.

With potatoes and oats I have not experimented so much. Judging from the past season's experience, it seems probable that the quantities of bone and potash salt I just mentioned, and about double the nitrogen, will make a good mixture. For oats I am inclined to make use of the same proportions as for corn, but I think smaller total quantities would do upon these crops. According to analysis, an oat crop takes less from the soil than one of corn, and my experience indicates that oats will do well with less manure. I expected the large quantities on some of the plots of the nitrogen experiment would make them lodge badly, but the weather or something else kept them up all right.

MR. SAGE'S EXPERIMENTS.

I wish likewise to call especial attention to the experiments of Mr. Sage, detailed in Table I of Appendix, in both of which potash has proved remarkably efficient; phosphoric acid added something to the yield, but nitrogen has been almost without effect. In an experiment in another trial not reported here, Mr. Sage found very similar results. One hundred and fifty pounds of muriate of potash made, as Mr. Sage says, the difference between a crop scarcely worth husking, and 60 bushels per acre of as fine corn as he could ask for.

MR. NEWTON'S EXPERIMENTS.

The experiments of Mr. Newton, detailed in Tables II and III, Appendix, are among the most interesting of all. The particular point in this case is the effect of nitrogen upon the corn. While in most cases the nitrogen has little or no effect, in Mr. Newton's trials it was the only effective ingredient; and the corn responded to it very uniformly wherever it was applied.

Had not so much space already been consumed, I should speak in detail of a number of other experiments; as those of Mr. Pierce, Mr. Hicks, Mr. Eliason, and others.

EXPERIMENTS OF MR. CLENDON.

I must, however, make at least brief reference to the experiments by Mr. Clendon, of Virginia, which are found in Table VIII of the Appendix. The most interesting point in Mr. Clendon's experiments is the effect of the raw or undissolved South Carolina phosphate. Concerning this, Mr. Clendon writes as follows:

Allow me to call particular attention to the benefits derived from the use of finely powdered but otherwise unmanipulated South Carolina rock. I have used it for several years in quantities varying from the single bag up to ten tons, and have become satisfied that in equal values it did as much good as the superphosphates; but until this year have not made comparative tests where the crops were weighed. * * *

It will be seen from the experiments that nitrate of soda and potash do not pay. Superphosphate of lime did well, but the South Carolina phosphate did better. An application of 400 pounds per acre gave an increase of over 19 bushels of shelled corn.

The soil is a decomposed gneiss, uniformly poor, and is a fair sample of hundreds of square miles lying between the base of the Blue Ridge and tide-water in Virginia.

On soils containing lime, superphosphate is rapidly reduced to an insoluble condition, and from its extreme fineness may be better than the raw phosphate; but judging from the softness of our spring water—for household purposes practically as soft as rain water—my soil contains very little lime, and a soluble phosphate may be positively injurious; and when not injurious may form the insoluble, inert phosphate of iron.

My experiments have been carried over ten years with uniform results. In every year the good effect of the raw phosphate was apparent. As South Carolina phosphate is so cheap, I think my experiments should be repeated over a wide country. I am aware that in some localities an insoluble phosphate is regarded as of no value. The same may be said of superphosphates. Experiment alone is the farmer's safety.

EXPERIMENTS OF PROFESSOR STUBBS.

These experiments are of especial interest from the fact of their being made with cotton, the study of which for the Southern States, is of incalculable importance. On receipt of Professor Stubbs's report, I wrote him a letter containing the following:

The results seem to me most interesting and valuable. The potash, as you say, appears to have very little effect, the nitrogen more, and the phosphoric acid most of all. In how far these results are decided by the soil and to what extent they are due to the feeding capacity of the plant are of course questions for further investigation. It is, however, interesting to note that, while the one-third nitrogen ration in each of the three nitrogen groups materially increases the yield, or at least appears to do so, instead of rising with the large applications of nitrogen, actually falls. I have put your figures together so as to show this.

Assuming the yield on Plot No. 7 with Fertilizer No. 6 to represent what would be the yield in each case with superphosphate and potash salt, we have yields of cotton and gains due to nitrogenous fertilizers as follows:

Nitrogenous fertilizer.	Amount of nitrogen.		
	24 pounds.	48 pounds.	72 pounds.
	Pounds.	*Pounds.*	*Pounds.*
Nitrate of soda	1,545	1,403	1,242
Sulphate of ammonia	1,115	1,265	1,162
Dried blood	1,357	1,300	1,127
Average of above	1,338	1,323	1,177
Mixed minerals	1,219	1,219	1,219
Gain from nitrogen	119	104	42
Cotton-seed meal	1,253	1,518	1,345
Mixed minerals	1,219	1,219	1,219
Gain from nitrogen	34	299	126

Thus in the nitrate of soda group, Nos. 8, 10, and 13, the No. 8, with 24 pounds of nitrogen per acre, shows increase of over 300 pounds over No. 6, "mixed minerals," while in Nos. 8 and 9 the amount decreases so as to show with 72 pounds of nitrogen in No. 9 no increase over No. 6. The results with the sulphate of ammonia group show practically no increase; indeed, if anything, a falling off of nitrogen. Nor are they much more favorable with dried blood: indeed here while there is a slight gain with the one-third ration, the others fall off until with the full ration there is a decided decrease as compared with the yield with no nitrogen at all.

In short one can almost say that the more nitrogen there is applied the less cotton is produced.

Of course if we had the four plots with "mixed minerals" instead of one, the comparison would be more reliable as an index of the gain with nitrogen. Still these figures agree very emphatically in testifying that the large quantities of nitrogen in the commercial forms were very unprofitable.

The figures for cotton-seed meal are striking. Lumping the gains with the several nitrogenous materials together, we have more with this than with either sulphates of ammonia or dried blood, and about the same as with nitrate of soda. Thus the total yields are:

Amount of ration.	Nitrate of soda.	Sulphate of ammonia.	Dried blood.	Cotton-seed meal.
	Bushels.	*Bushels.*	*Bushels.*	*Bushels*
One-third ration	15.45	11.15	13.57	12.53
Two-third ration	14.03	12.65	13.00	15.18
Full ration	12.42	11.62	11.27	13.45
Sum	41.90	35.42	37.84	41.16

That is to say, according to the testimony of this experiment:

1. In return for 24 pounds of nitrogen per acre in commercial fertilizers, which would cost, near the large seaboard markets, at present prices, cash, say (24 pounds, at 25 cents per pound), $6, and in the interior, on time, a good deal more, you get, on the average, 119 pounds of cotton. When you double the amount of nitrogen you get less increase; trebling it, you have a loss.

2. But when, instead of using these imported products, you put back on your land the cotton seed it has already produced, enough to furnish the same quantity of nitrogen (about two pounds of cotton-seed meal for one of nitrate of soda, and three for one of sulphate of ammonia), you get as much as with the nitrate of soda and more than with anything else.

Of course, no wise man will proclaim a general principle from a single series of experiments. Still these results are certainly striking and suggestive. There are two questions in particular which they suggest anew to me, as doubtless they have done to you.

First. Where, how, and in what quantities can nitrogen be used with profit to grow cotton?

Second. If this element, which is already scarce and costly, and growing scarcer and costlier year by year, is necessary to make cotton grow, is it better for planters to send their money to distant dealers who must search the North, East, and West, and even send to foreign lands to obtain it, or to utilize a home product that furnishes the nutrition at vastly less cost and a lot of phosphoric acid and potash besides? The farmers and planters of Georgia and other Southern States are importing millions of dollars' worth of nitrogen every year. Is this wise, and how can the question as to the economy be solved otherwise than by direct experiment?

I have thus hastily and crudely set down some of the things that first occur to me from very brief study of your experiment. My object is not to assume the position of interpreter, but rather to inquire if these ideas agree with your own, and to ask if you will not kindly favor me with your own interpretations and suggestions. I should regard it as an especial favor if you would furnish me your comments for publication with your experiment.

To this Professor Stubbs replied as follows:

I refrained from the discussion of the result of the experiments *in extenso*, because I have discussed the questions involved in an official report now in press. In making this series of experiments I had the following questions in view:

1st. Which of the valuable ingredients of manure, nitrogen (or ammonia), phosphoric acid, and potash, are needed by cotton on our soil?

2d. Which form of nitrogen is best adapted to the requirements of cotton, the nitrogen being furnished in the form of nitrate of soda, sulphate of ammonia, dried blood, and cotton-seed meal?

3d. If nitrogen is needed, what amount is necessary to make a maximum crop at greatest profit?

Nearly all of these questions were decided to my own satisfaction by a series of carefully conducted experiments extending through five years on my plantation near this place, several years since. They have been repeatedly published, all tending to show that *our soil* results from disintegration of metamorphic rocks, principally hornblendic and feldspathic, showing—

1st. No need of potash for cotton.

2d. Decided need of phosphoric acid in soluble forms.

3d. A small advantage from nitrogen in moderate quantities.

Upon soils rich in vegetable matter, the last deduction may be amply modified, but our great want for cotton, and it seems to prevail throughout the older cotton States, is soluble phosphoric acid. On worn-out soils a small amount of nitrogen also seems to be required.

The most favorable proportion seems to be about three parts nitrogen to ten of phosphoric acid. Cotton-seed meal has been practically tested by myself alongside of other nitrogenous material, time and again, and has always proved equal in fertilizing value, and cost less than other nitrogenous fertilizers. So decided have been the results of these experiments that for four years I have not bought an ounce of manipulated guano or chemical salts, other than dissolved bone and cotton-seed meal. A mixture of these two furnishes a manure for cotton, which, I think, cannot be surpassed by any other mixture. I have found but one other equal or superior to it, and that is a compost of cotton-seed, stable manure, and dissolved bone.

In speaking further of the poor economy of purchasing nitrogenous material outside, and the better policy of using cotton-seed, Professor Stubbs continues:

Let us compare results. A fertilizer containing 3 per cent. of nitrogen and 10 per cent. of available phosphoric acid, sells here for $45 per ton cash, or for a bale of cotton on time. A fertilizer made of equal parts of a high grade of dissolved bone, costing here $30, and showing 14 or 16 per cent. of available phosphoric acid, and cotton-seed meal which, costing $20 per ton, will contain 3½ per cent. of nitrogen, and 8½ to 9½ per cent. of available phosphoric acid, and will cost $25 per ton. Hence you get nearly two tons of the latter, strictly pure, at the cost of one of former, which would be up to the standard. I use annually 20 tons of the mixture, which costs me less than $20 per ton, while my neighbor, who buys on time, pays 20 bales of cotton for the same amount, and here is the secret of failure to use cotton-seed meal in larger quantities as a manure. It sells for cash, and our cotton planters buy little or nothing that way.

Nearly all of our cotton-seed meal goes to Europe and North to be used for feeding, while both our lands and our stock cry out against this unnatural deprivation. But a change is gradually being wrought. Already a large company is operating in this State manufacturing a high grade of goods out of cotton-seed meal and a high grade of dissolved bone. But they sell on time, and will, I expect, make a large profit. So much for results of other experiments of which these are confirmatory. Now to experiments themselves. 1st. Potash gives no increase. 2d. Phosphoric acid brings decidedly good returns. 3d. Nitrogen increases the yield a little. 4th. Increase of the nitrogen is practically of little use even if not detrimental. 5th. Cotton-seed meal is decidedly the cheapest form of nitrogen. These are my conclusions from experiments. Let us discuss them.

1st. In experiment No. 4 (potash alone) the yield is less than No. 1 (with nothing) just the difference, I think, between the natural fertility of the two plots.

2d. Phosphoric acid increased every yield where it was used, and this has been the universal result of all experiments in cotton in North Carolina, South Carolina, Georgia, and Alabama. (In black, cretaceous prairie cotton belt of latter State fertilizers have not been used as yet, and hence this area is not included in assertion. Will try some this year on these soils to test this question.)

Phosphoric acid has the decided tendency in cotton to make fruit, so much so that in Experiments 2 and 3, until they began to fruit, no difference in appearance was perceptible. As soon as they began to take on "squares" the difference was very perceptible. Again, phosphoric acid has a decided tendency to hasten maturing, an important item here, since the caterpillar almost invariably more or less injures our late cotton.

3d and 4th. Nitrogen alone increases the crop only a little. This it does by increasing size of plant and thus enabling it to grow larger and more extended roots, by virtue of which a larger amount of phosphoric acid is gathered, which really increases the ultimate production; but the land is always overcropped thereby, and shows evidence of it the next summer. For the same reason, on most soils, a small addition of nitrogen to dissolved bone is beneficial, since its increase of roots and stalks enables the plant to utilize the phosphoric acid more completely, and perhaps also to draw an extra quantity from the soil; but if an extra amount of nitrogen is used, the organs of vegetation are developed too long into the season to admit of a large crop. This is especially true during a wet season. All the energy of the plant is exerted in making vegetation, and often the frost catches it just as it begins to fruit well. This is especially true of cotton, since it is a perennial plant, and if furnished with excess of nitrogen will continue to grow, making but little fruit, until checked by drought or cold. Farmers in rich bottom correct this tendency by topping. In this way I readily account for loss where two or three rations were used. All those experiments where two and three rations of nitrogen were used were green, growing, blooming, fruiting, and luxuriant when killed by frost. Further evidence can be found in amounts picked at various times: while nearly three-fourths of Experiments 3, 5, 7, 8, 9, 14, 17, and 22 were gathered by October 1, Nos. 10, 13, 14, 12, 16, 17, 19, and 20 not one-half and in some instances not one-third were gathered by that time. Again, with these larger rations of nitrogen, should a severe drought prevail, the plant is always burned or "rusted" to a disastrous extent, and hence loss.

Either horn of dilemma is dangerous. Extremly propitious seasons, with frost deferred till winter, only can insure a success with large quantities of nitrogen, and then only when phosphoric acid is furnished in larger quantities, either by the soil or artificially. Just here let me remark that the cotton plant is worthy of a thorough scientific study. It has a large leaf surface, endowed with power to assimilate a large quantity of nitrogen when grown on a poor soil. If, as it has been asserted, every plant is capable of assimilating the nitrogen of air in proportion to extent of leaf surface, then cotton should stand in the front rank as a "green manuring crop," and this is claimed for it by some.

In a published report of these experiments, Professor Stubbs compares in detail the effects of nitrogen in different forms and combinations as compared with its cost, and concludes as follows:

Hence the value of nitrogen in cotton-seed meal as a fertilizer for cotton is but little inferior, if not equal, to nitrogen in that form which is universally acknowledged to be the best and highest, viz., nitrate of soda. Therefore, I say with proper economy, with proper utilization of his own cotton seed, supplemented by such home-made manures (rich in nitrogen), as can be made and saved upon every plantation, the southern planter needs no imported nitrogen to grow his crops.

When we remember the proximity of the large phosphatic beds of Charleston, S. C.,

out of which are made nearly all of the superphosphates which supply our soils with that much needed ingredient, phosphoric acid; when we remember that our chief staple can be furnished with all the needed nitrogen from home sources, and that potash, when needed, can be obtained from the ashes of our extensive forests, thus furnishing from southern soil all the needful ingredients to grow our southern staple, it is with feelings of pride and pleasure that we contemplate the vast capabilities and magnificent possibilities of southern agriculture in the near future.

PENNSYLVANIA AGRICULTURAL COLLEGE—EXPERIMENTS BY PROFESSOR JORDAN.

A series of experiments, upon a plan closely according with that of the "special nitrogen experiments" above described, was instituted in 1881 upon two of the experimental farms of the Pennsylvania Agricultural College by Prof. W. H. Jordan, formerly of the Maine State College, whose experiments on the farm of the last-named institution have already been mentioned. (See Appendix Tables I and VIII.)

The following accounts of the Pennsylvania experiments are quoted from advance sheets of Professor Jordan's report for 1881, kindly furnished for the purpose:

PLAN OF THE EXPERIMENTS.

The general plan of the experiments herewith reported is as follows: The fertilizers are to be used on a rotation of crops, each rotation occupying four years. The order will be corn, oats, wheat, and grass. The fertilizers to be applied only twice during each rotation to the corn and wheat. The plots are accurately measured, and the fertilizers used and the crops produced are in each case carefully weighed. The same fertilizers are to be applied to the same plots each time, several plots not receiving any fertilizer at all. The various manures used will be phosphatic, potassic, nitrogenous, and mixtures of two or all three of these; yard manure alone and with lime; lime, ground limestone, and plaster.

The points to be given special attention are the following:

First. The necessary ingredients of a fertilizer for continued use, with especial reference to the nitrogen supply.

Second. The relative effect of the same fertilizer upon different crops.

Third. The relative effect of a continued use of commercial fertilizers and of yard manure.

Fourth. The benefits of lime, ground limestone, and plaster.

The experiments conducted the past season were with corn and oats on the central farm, and with corn on the eastern farm.

REPORT OF EXPERIMENT WITH OATS ON THE CENTRAL FARM, 1881.

Conditions of experiment.—The soil of the experimental plots on this farm is essentially a "limestone clay." It is rather tenacious and heavy when wet, but dries off rapidly after a rain, the natural drainage being good. The plots on which the oats were sown were planted to corn in 1880. Previous to that the land had grown a rotation of crops, but had received no manure for five years. In 1880 the plots all received an application of yard manure, with the exception of one or two. Although the plots had been used for experimental purposes previous to this year, the differences in the manuring was so slight in most cases, and so much time had elapsed since the application of any manure, it is believed that the results are not seriously affected by previous conditions, especially as in the past the treatment of

the plots pertained mostly to methods of plowing, and of care of the crops, rather than to radical differences in the manures used.

The size of the plots is 260 feet long by 21 feet wide, each containing one-eighth of an acre.

In the experiment on oats, the method of cultivation, time of sowing, amount of seed, and time of cutting were the same for all the plots.

The land was plowed in the spring, after which the commercial fertilizers were sown broadcast and harrowed in, the yard manure having been spread on the sod and plowed under. The lime, ground limestone, and plaster were also sown, and harrowed in after plowing. Four quarts of Excelsior oats were sown on each plot, or at the rate of two bushels per acre. The seed was sown in April 22, and the oats were cut July 18.

In the following table are shown the arrangement of the plots, the kinds and quantities of fertilizers applied per acre, the quantities of valuable ingredients contained in the fertilizers, and the yield of oats and straw per plot and per acre.

The percentages of valuable ingredients in the materials used were as follows: Dissolved bone, 16 per cent. available phosphoric acid; muriate of potash, 50 per cent. potash; dried blood, 10 per cent. nitrogen; nitrate of soda, 15 per cent. nitrogen; sulphate of ammonia, 20 per cent. nitrogen. The yard manure was that produced by fattening steers fed upon corn meal and corn fodder. It contained considerable litter.

TABLE A—*Showing results of experiment with fertilizers on oats, conducted at the central farm.*

	Number of plot.	Kind of fertilizer.	Quantity of fertilizer per acre.	Quantities of valuable ingredients applied per acre. Nitrogen.	Phosphoric acid.	Potash.	Production per plot. Oats.	Straw.	Production per acre. Oats.	Straw.
			Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Bush.*	*Lbs.*
	1	Nothing					148	387	37	3,096
A.—Valuable ingredients singly.	2	Dried blood	320	32			155	485	38.7	3,880
	3	Dissolved bone	300		48		173	535	43.2	4,280
	4	Muriate of potash	200			100	172	538	40	4,304
B.—Valuable ingredients two by two.	5	Dissolved bone	300		48		177	550	44.2	4,400
		Dried blood	320	32						
	6	Muriate of potash	200			100	152	416	38	3,328
		Dried blood	320	32						
	7	Dissolved bone	300		48		150	480	37.5	3,840
		Muriate of potash	200			100				
	8	Nothing					115	300	28.8	2,400
C.—Complete fertilizer, † with nitrogen in different proportions; nitrogen furnished by dried blood.	9	Mixed minerals*			48	100	198	565	49.5	4,520
		Dried blood	240	24						
	10	Mixed minerals*			48	100	203	620	50.7	4,960
		Dried blood	480	48						
	11	Mixed minerals*			48	100	207	650	51.7	5,200
		Dried blood	720	72						
	12	Mixed minerals*			48	100	190	610	47.5	4,880
		Dried blood	240	24						
	13	Plaster	320				167	480	38.6	3,840
	14	Nothing					169	490	39.1	3,920
D.—Commercial fertilizers and yard manure compared—fertilizers as in C.	15	Mixed minerals*			48	100	206	585	51.5	4,680
	16	Yard manure	12,000	52.4	25	60.4	179	545	44.7	4,360
	17	Mixed minerals*			48	100	199	620	49.7	4,960
		Dried blood	240	24						
	18	Yard manure	16,000	72	34	83	187	565	46.7	4,520
	19	Mixed minerals*			48	100	211	710	52.7	5,680
		Dried blood	480	48						
	20	Yard manure	20,000	90	42	104	200	586	50	4,688
	21	Mixed minerals*			48	100	228	735	57	5,880
		Dried blood	720	72						
E.—Effect of lime.	22	Yard manure	12,000	52.4	25	60.4	204	600	51	4,800
		Lime	500							
	23	Lime	500				196	560	49	4,480
	24	Nothing					188	568	47	4,524
F.—Complete fertilizer, † with nitrogen in different proportions; nitrogen furnished by nitrate of soda.	25	Mixed minerals*			48	100	225	715	56.3	5,720
	26	Mixed minerals*			48	100	254	815	63.5	6,520
		Nitrate of soda	160	24						
	27	Mixed minerals*			48	100	205	715	51.3	5,720
		Nitrate of soda	320	48						
	28	Mixed minerals*			48	100	198	720	49.5	5,760
		Nitrate of soda	480	72						
G.—Complete fertilizer, † with nitrogen in different proportions; nitrogen furnished by sulphate of ammonia.	29	Mixed minerals*			48	100	248	740	62	5,920
	30	Mixed minerals*			48	100	249	772	62.5	6,176
		Sulphate of ammonia	120	24						
	31	Mixed minerals*			48	100	218	762	54.5	6,096
		Sulphate of ammonia	240	48						
	32	Mixed minerals*			48	100	229	754	57.3	6,032
		Sulphate of ammonia	360	72						
	33	Plaster	320				184	548	46	4,384
	34	Ground limestone	500				198	582	49	4,656
	35						210	680	52.5	5,440
	36	Nothing					184	652	46	5,216

*The term "mixed minerals" is used to designate the fertilizers applied to Plot 7, viz, dissolved bone, 300 pounds per acre, and muriate of potash, 200 pounds.

† A combination of dissolved bone, muriate of potash, and some nitrogenous fertilizer.

In the next table are given the average results where several plots are manured in essentially the same manner. For instance, there are four sets (C, D, F, and G of previous table) of plots in which mineral fertilizers alone (fertilizers containing phosphoric acid and potash, but no nitrogen), and the same, combined with varying quantities of nitrogen, are used, the only difference being that the nitrogen is not furnished by the same material in every set.

In order to see the effect of using no nitrogen, or of using it in small or large quantities, the average of these four sets of plots is given.

Three plots (16, 18, and 20 of previous table) were manured with barn-yard manure, and the figures given represent their average production.

It is believed that these averages represent very fairly the effect of the various fertilizers, as the plots receiving no fertilizer and those manured alike are quite well distributed over the experimental ground.

TABLE B—*Summary of Table A.*

	Kind of fertilizer.	Quantities of valuable ingredients applied per acre.			Yield per acre.		Increase over yield, with no fertilizer.		Pecuniary results.*	
		Nitrogen.	Phosphoric acid.	Potash.	Oats.	Straw.*	Oats.	Straw.	Cost of fertilizer per acre.	Value of increase per acre.
		Lbs.	*Lbs.*	*Lbs.*	*Bus.*†	*Lbs.*	*Bus.*†	*Lbs.*	‡	
Average of. 5 plots.	Nothing	......	......	......	39.6	3,830	......	......	......	......
One plot...	Dried blood	32	..	....	38.7	3,880	—0.9	50	$7 50	......
One plot...	Dissolved bone	......	48	......	43.2	4,280	3.6	450	5 25	$2 92
One plot...	Muriate of potash	......	......	100	40.	4,304	0.4	474	4 50	1 38
One plot...	Dried blood; Dissolved bone	32	48	......	44.2	4,400	4.6	570	10 88	372
One plot...	Dried blood; Muriate of potash	32	....	100	38	3,328	—1.6	-502	10 18	......
Average of 4 plots.	Dissolved bone; Muriate of potash.§	......	48	100	51.8	5,040	12.2	1,210	9 75	9 13
Average of. 4 plots.‖	Mineral fertilizers & smallest amount of nitrogen	24	48	100	56.3	5,529	16.7	1,699	15 38	12 80
Average of. 4 plots.‖	Mineral fertilizers and medium amount of nitrogen.	48	48	100	52 3	5,619	12.7	1,789	21 00	10 84
Average of. 4 plots.‖	Mineral fertilizers and largest amount of nitrogen.	72	48	100	53.9	5,718	14.3	1,888	26 64	11 87
Average of. 3 plots.‖	Yard manure.¶	72	34	82½	47.1	4,522	7.5	692	**8 00	5 48
Average of 2 plots.	Plaster	......	......	......	42.3	4,105	2.7	275	1 00	2 05
One plot...	Lime (caustic)	.....	......	......	49	4,480	9.4	650	10 00	7 30
One plot...	Ground limestone	......	.....	......	49	4,656	9.4	826	10 00	7 76

† Estimated on the basis of 32 pounds to the bushel.
* The oats are reckoned at $0.50 per bushel, and the straw at $5 per ton.
§ The same as "mineral fertilizers." Wherever the term "mineral fertilizers" occurs, it means 300 pounds dissolved bone and 200 pounds muriate of potash to the acre.
‖ In two sets of plots the nitrogen was furnished by dried blood, in one by nitrate of soda, and in one by sulphate of ammonia.
¶ Composition assumed to be the same as that given in Wolff's tables for fresh yard manure. The composition assumed is very nearly like that of stable manure as analyzed at the Connecticut Experiment Station.
‡ The cost of fertilizers per acre is not based upon their actual cost at the college, but upon what is a fair price at points easy of access. $5 per ton is allowed for transportation and handling.
** Based upon the cost near the college, viz., about one dollar per ton. Near cities the price would be $4 per ton, at least.

There are a few points that can be noted with profit, even in the results of one year's experiment :

1. The comparative inefficiency of the commercial fertilizers, containing but a single valuable ingredient, as the dried blood, dissolved bone, or muriate of potash.

2. The combination of phosphoric acid and potash (mineral fertilizers) caused a much better yield than either alone, and nearly as great a yield as when nitrogen was added.

3. Anything more than a small quantity of nitrogenous fertilizer, combined with the mineral fertilizers, failed to produce an increase of crop. There seemed to be no difference in this respect between the dried blood, the nitrate of soda, or the sulphate of ammonia, used to furnish the nitrogen. This failure of nitrogenous fertilizers, whether used on grain or corn, to do any better with 72 pounds of nitrogen to the acre than with 24 pounds, is in accordance with a large number of results arrived at in experiments under the direction of Prof. W. O. Atwater. (Report of Connecticut State Board of Agriculture, 1880.)

Mr. J. B. Lawes, the noted English experimenter, thinks that we fail to see marked results follow the use of nitrogenous fertilizers on grain simply because there is such a store of organic nitrogen in the soil that the plants receive sufficient supply without the aid of artificial manures. If these experiments be continued through a series of years, supplying the same plots each time with mineral fertilizers alone, and other plots with mineral fertilizers and nitrogen, the capacity of the soil and air for furnishing a continuous necessary quantity of nitrogen will be tested. It is the plan to do this on the college farms. It is certain that the crop produced by mineral fertilizers alone succeeded in getting not far from 60 pounds of nitrogen without the aid of manure of any sort. Below is a table showing the amount of nitrogen supplied by the fertilizers, the amount taken up by the crop, and the increased amount taken up because of the use of the various manures:

Kind of fertilizers.	Quantity of nitrogen supplied in the fertilizers.	Quantity of nitrogen taken up by grain and straw.	Excesss of nitrogen taken up because of fertilizers of grain and straw.
	Pounds.	*Pounds.*	*Pounds.*
Nothing	....	45.8	....
Mineral fertilizers	....	59.6	13.8
Mineral fertilizers and one-third quantity nitrogen	24	65.4	19.6
Mineral fertilizers and two-thirds quantity nitrogen	48	63.3	17.5
Mineral fertilizers and three-thirds quantity nitrogen	72	64.7	18.9
Yard manure	72	54	8.2

In calculating the above table it is assumed that the grain and straw have the same composition for all the plots. Probably the percentage of nitrogen is higher for those plots receiving nitrogenous fertilizers than in the others, but the difference would not be so large as to destroy the value of the above comparison.

One practical point involved in the use of nitrogenous fertilizers is that of their great cost. One pound of nitrogen costs as much as two pounds of phosphoric acid or four pounds of potash. Its presence in a commercial fertilizer in any quantity increases largely the cost of that manure. If this expense can be avoided for the present at least, it will be a great saving to the farmer.

4. The yard manure failed to produce as large a crop of either grain or straw as did the mineral fertilizers or the complete fertilizer (mineral fertilizers combined with nitrogenous).

As the manure was but little decomposed when applied, it is not strange that it failed to furnish a large amount of plant food. It is generally believed that the effect of yard manure extends over a longer period of time than that of commercial fertilizers, a large part of its benefit being felt by the second or even third crops after its application. The crops on these plots for the next few years will, probably, throw some light on this point.

5. The plaster, lime, and ground limestone did not seem to materially increase the crop over that of adjacent plots which received no manure. Neither did the ground limestone seem to possess any advantages over the burned lime.

6. None of the fertilizers paid for themselves, not even the yard manure at one dollar per load of two thousand pounds. The profits resulting from the use of the fertilizers cannot be estimated until one or perhaps two rotations are past. The land is now in pretty good condition, and is capable of nourishing a fair crop without the aid of manure, but those plots not fertilized will undoubtedly begin to show the effect of cropping after several years, whereas the plots manured will be kept up to a good standard. When that time arrives the effect of the fertilizers will be more marked.

These plots were manured exactly as for oats, and were sown to wheat in September. There is already a marked difference in the growth of the wheat on these various plots. The result will be reported in due time.

If space permitted, I should be glad to quote in detail the accounts of other experiments by Professor Jordan. It seems necessary, however, to give only a general summary.

EXPERIMENT WITH CORN ON THE CENTRAL FARM, 1881.

Conditions of experiment.—The kind of soil, previous treatment, size of plots, and method of application of fertilizers, were, as in the experiment on oats above described, "only in the case of the plots used for the corn there had been no manure of any kind applied to the land for five years. The plots which were in a partial clover sod were plowed in the spring, a short time before planting the corn." The fertilizers were the same and applied in exactly the same order as in the oat experiment.

"The growth of the crop was checked by the drought, extending through July, August, and September. At no time during the season could any difference be seen in the development of the corn on the various plots, either as to quantity of growth or in any other particular."

The following table gives a summary of results, as was done in Table B with results of experiments with oats:

TABLE C.—*Summary of experiment with corn.*

	Kind of fertilizer.	Quantities of valuable ingredients applied per acre.			Yield per acre.		Increase over yield with no fertilizers.	
		Nitrogen.	Phosphoric acid.	Potash.	Corn.	Stover.	Corn.	Stover.
		Lbs.	*Lbs.*	*Lbs.*	*Bus.*	*Lbs.*	*Bus.*	*Lbs.*
Average of 5 plots	Nothing	.....	.....	.....	33	2,373	.....	.....
One plot	Dried blood	32	.....	.....	34.7	2,576	1.7	203
One plot	Dissolved bone	.....	48	.....	35.2	2,480	2.2	107
One plot	Muriate of potash	.....	.....	100	35.7	2,640	2.7	267
One plot	Dried blood, dissolved bone.	.....	48	100	37.8	2,440	4.8	67
One plot	Dried blood, muriate of potash.	32	.....	100	35.2	2,800	2.2	427
Average of 5 plots	Dissolved bone, muriate of potash. †	.....	48	100	35	2,292	2	—81
Average of 4 plots	Mineral fertilizers, and smallest amount nitrogen.	24	48	100	34.5	2,248	1.5	—125
Average of 4 plots	Mineral fertilizers, and medium amount nitrogen.	48	48	100	32.9	2,224	.....	—149
Average of 4 plots	Mineral fertilizers, and largest amount nitrogen.	72	48	100	30.1	2,236	—2.9	—143
Average of 3 plots	Yard manure	72	34	83	37.7	2,208	4.7	—165
Average of 2 plots	Plaster	.....	.....	.....	31.8	2,260	—1.2	—113

* Shelled corn.

† Same as "mineral fertilizers."

EXPERIMENTS WITH CORN, EASTERN EXPERIMENTAL FARM, 1881.

The following experiment, also reported by Professor Jordan, was conducted by Mr. J. Fremont Hickman, superintendent Eastern Experimental Farm, West Grove, Pa. The plan, it will be noticed, is essentially similar to that of the nitrogen experiments described above. (See Table III in appendix.)

The plots upon which the experiments were made were of equal size, viz., one-twentieth of an acre each. The ground was a sod of three years' standing, without having received fertilizers of any kind.

Mr. Hickman's observations regarding growth and appearance of the corn, and the temperature and rain-fall, are so much to the point that I quote them in full:

OBSERVATIONS.—During the growth of these plots careful observations were taken every two weeks. Previous to the first of July no appreciable difference could be detected in their general appearance, but from that time on until the maturing of the crop, some slight differences were noticeable. No. 3, the plot having dissolved bone black alone, was noticed to have a more uniform growth and a greater average height than any plots near it. No. 5, the plot having dissolved bone black and dried blood was noted as being better in appearance than any that preceded it. In No. 8 the absence of a fertilizer was very plainly marked. No. 11 had the advantage of a more healthy color than No. 12, but the growths seemed about equal. The addition of sulphate of ammonia to plots 18, 19, and 20, was noted as being apparently without effect. The differences above noted were apparently continued until the maturing of the corn. The slight differences in appearance during growth and in the final results I do not hesitate to attribute to the extremely dry weather of the corn season. There follows a summary of the temperature and rain-fall for the season.

TEMPERATURES AND RAIN-FALL.—We have been careful to record the temperatures of the weather regularly three times each day, viz., at 7 a. m., at 2 p. m., and 9 p. m. Having these temperatures, and also the amount of rain-fall, we have calculated the average temperature of each month, which we will give in connection with the amount of rain-fall:

Months.	Average temperature.	Total rain-fall.
	°F.	*Inches.*
May	66.3°	3.18
June	69.0°	5.87
July	77.5°	0.56
August	77.8°	0.70

From the above it will be readily seen that the first two months of the corn season—May and June—were favorable for a maximum crop, and up to the last of June the appearance of the corn crop was very promising. But during the two following months—July and August—the weather being very warm and extremely dry, the corn suffered very much, and the result was almost an entire failure.

TABLE D.—*Results of experiments with corn, Eastern Farm.*

	Number of plot.	Kind of fertilizer.	Quantities of fertilizers per acre.	Quantities of valuable ingredients applied per acre. Nitrogen.	Phosphoric acid.	Potash.	Yield of ears of corn per plot.	Yield of shelled corn per acre.
			Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Pounds.*	*Bushels.*
	1	Nothing	....	....	....	....	67.5	18
A.—Valuable ingredients, singly.	2	Dried blood	240	24	....	....	68.5	18.3
	3	Dissolved bone	300	....	48	....	84.5	22.5
	4	Muriate of potash	200	....	....	100	58.8	15.7
B.—Valuable ingredients, two by two.	5	Dried blood	240					
		Dissolved bone	300	24	48	....	86	22.8
	6	Dried blood	240					
		Muriate of potash	200	24	....	100	82.3	22
	7	Dissolved bone	300					
		Muriate of potash	200	....	48	100	74	19.6
	8	Nothing	....	....	....	....	62.3	16.6
C.—Complete fertilizer,† nitrogen in varying proportions from dried blood.	9	Mineral fertilizers,* dried blood.	240	24	48	100	60	16
	10	Mineral fertilizers, dried blood.	480	48	48	100	77.3	20.6
	11	Mineral fertilizers, dried blood.	720	72	48	100	67.8	18
D.—Complete fertilizer, nitrogen in varying proportions from nitrate of soda.	12	Mineral fertilizers	....	....	48	100	67	17.8
	13	Mineral fertilizers, nitrate of soda.	160	24	48	100	65.5	17.4
	14	Mineral fertilizers, nitrate of soda.	320	48	48	100	76	20.4
	15	Mineral fertilizers, nitrate of soda.	480	72	48	100	79.3	21.1
	16	Nothing	....	....	....	....	69.3	18.5
E.—Complete fertilizer, nitrogen in varying proportions from sulphate of ammonia.	17	Mineral fertilizers	....	....	48	100	69.8	18.6
	18	Mineral fertilizers, sulphate of ammonia.	120	24	48	100	70	18.6
	19	Mineral fertilizers, sulphate of ammonia.	240	48	48	100	67.8	18
	20	Mineral fertilizers, sulphate of ammonia.	320	72	48	100	70.3	18.8
	21	Yard manure	12,000	52.4	25	60.4	70.5	18.8
	22	Plaster	320	....	....	....	65.3	17.4

* Same as plot 7. † Containing all the valuable ingredients.

The following is a summary of the results as given in the previous tables:

TABLE E—*Summary of Table D.*

	Kind of fertilizer.	Quantities of valuable ingredients applied per acre. Nitrogen.	Phosphoric acid.	Potash.	Yield of shelled corn per acre.	Increase of yield per acre over no fertilizer.
		Pounds.	*Pounds.*	*Pounds.*	*Bushels.*	*Bushels.*
Average of 3 plots	Nothing	....	....	....	17.7	....
One plot	Dried blood	24	....	....	18.3	0.6
One plot	Dissolved bone	....	48	....	22.5	4.8
One plot	Muriate of potash	....	....	100	15.7	—2.0
One plot	Dried blood; dissolved bone	24	48	....	22.8	5.1
One plot	Dried blood; muriate of potash	24	....	100	22	4.3
Average of 3 plots	Dissolved bone; muriate of potash	....	48	100	18.6	0.9
Average of 3 plots	Mineral fertilizers and smallest amount nitrogen.	24	48	100	17.3	—0.4
Average of 3 plots	Mineral fertilizers and medium amount nitrogen.	48	48	100	19.6	1.9
Average of 3 plots	Mineral fertilizers and largest amount nitrogen.	72	48	100	19.3	1.6
One plot	Yard manure	52.4	25	60.4	18.8	1.1
One plot	Plaster	....	....	....	17.4	0.3

Professor Jordan summarizes the results of his experiments as follows:

None of the fertilizers produced any material increase of crop, not even the farmer's old "stand-by," yard manure. So long as this is the case, we cannot discuss the relative effect of the different fertilizers, for none of them had any effect. All the good we can hope to gain then from the experiments is, to discover, if possible, whether anything in the method of cultivation or the application of the fertilizers was the cause of their not producing any effect. If the peculiar conditions of the season were responsible for the failure of the various manures to act, it is equally important to know what were the exact causes operating to induce such a result. Below is a summary of the temperatures and rain-fall at the two farms, the figures for the Central Farm being kindly furnished by Prof. C. Alfred Smith.

Months.	Central farm.		Eastern farm.	
	Average temperature.	Total rain-fall.	Average temperature.	Total rain-fall.
	° F.	*Inches.*	° F.	*Inches.*
May	67	2.82	66.3	3.18
June	68	6.82	69.0	5.87
July	79	2.83	77.5	0.56
August	76	0.86	77.8	0.70
September	78	0.60	....	....

It is to be noticed that the temperatures for July and August are very high, while the amount of rain-fall is very small.

The extreme dryness, caused by the great heat and the lack of rain-fall, is undoubtedly the direct cause of no increase crop resulting from the use of the fertilizers. As the commercial fertilizers were sown broadcast, and as the yard manure used was not fermented, we should not expect either kind of fertilizer to have much effect until after considerable root development had taken place, or until the more advanced stages of growth. When that time arrived the lack of soil water prevented a growth at all commensurate with the supply of food available to the plants. In other words, water was the missing ingredient of plant-food, so that no matter how much else might be present for use it could not be utilized. Such an explanation is, of course, of the most general nature. Only after the experiments of several years can one be offered more in detail.

In brief, Professor Jordan's experiments of 1881 were so affected by severe drouth that none of the fertilizing materials brought much increase. But the experiments are rationally planned, the questions studied are specific and not numerous, the work is being thoroughly done, accurate observations are made of the numerous conditions, including especially the weather, and the trials are to be continued through a series of years with crops succeeding one another in regular rotation.

We have here a rational, systematic, and thorough series of investigations, comparable with each other and with similar ones elsewhere. The outcome cannot fail to be of great value.

As regards the effects of nitrogen upon the growth of corn, the results of the one season's experiments, as far as they go, accord with those elsewhere obtained, in that the corn gives very little response to nitrogen. Indeed, in some of the trials, less of both corn and stalks

was obtained with the nitrogenous fertilizers than without them. The same result was noticed in several of the nitrogen experiments previously described. (Appendix. Tables I to III.)

The oats paid more heed to the nitrogen, though the increase was small, only four bushels per acre, with the smallest ration, 24 pounds per acre, and even less with the larger quantities of nitrogen.

EXPERIMENTS BY MR. SANBORN, OF THE NEW HAMPSHIRE AGRICULTURAL COLLEGE.

Mr. J. W. Sanborn, farm superintendent of the New Hampshire Agricultural College at Hanover, has been conducting, for some four years past, on the farm of that institution, several series of field experiments, in one of which the effects of phosphatic, potassic, and nitrogenous fertilizers have been studied in a method analogous to that of the Special Nitrogen Experiments above detailed.

The experiments were begun in 1878, and have been continued, with the same fertilizers and crops on the same plots, to the present. The plots were each four rods long and two rods wide, and separated by vacant spaces. The crops have been corn and potatoes. The plan may be seen in the following table from Mr. Sanborn's report for 1879, which includes so much of one of the experiments, that with corn, as has a direct bearing upon the question of the nitrogen supply.

The soil is described by Mr. Sanborn as "an alluvial, undrained, clayey soil," "not well adapted to potatoes," and one on which "corn does not follow corn successfully." Before the experiment it had been in grass, and was in condition to yield 1½ tons of hay per acre. The season of 1879 was "cold in the spring and backward and dry during the formation and early development of the ear." Some of the results obtained in 1878 are included in the table with those of 1879:

Experiment with corn, 1879, by Mr. J. W. Sanborn.

Plots.	Materials used.	Furnishing.	Yield sound corn, bushels.	Yield soft corn, bushels.	Total yield, bushels.	Yield 1878.	Yield over nothing plot, 1879.	Yield over nothing plot, 1878.	Cost of fertilizer.	Value of corn.	Value of corn and stover.	Value of increase, corn and stover.	Stover, pounds.	Pounds stover to bushel corn.
28	186 pounds dissolved bone-black 128 pounds muriate potash 320 pounds sulphate ammonia	31 pounds phosphoric acid 67 pounds potash 64 pounds nitrogen	29.4	16.4	45.8	69	17	38	$21 33	$34 35	$45 28	$18 61	5,400	118
29	186 pounds dissolved bone-black 128 pounds mu iate potash 240 pounds sulphate ammonia	31 pounds phosphoric acid 67 pounds potash 48 pounds nitrogen	44.7	16.4	61.1	65	32.3	34	17 53	42 32	62 84	36 17	6,640	10.9
30	186 pounds dissolved bone-black 128 pounds muriate potash 160 pounds sulphate ammonia	31 pounds phosphoric acid 67 pounds potash 32 pounds nitrogen	50.6	14	64.6	53.3	35.6	22.5	13 73	46 08	64 68	38 01	6,200	96
31	186 pounds dissolved bone-black 128 pounds muriate potash 80 pounds sulphate ammonia	31 pounds phosphoric acid 67 pounds potash 16 pounds nitrogen	55.5	13.5	69	48	40.2	17	9 93	49 80	68 70	42 03	6,300	91
32	186 pounds dissolved bone-black 128 pounds muriate potash	31 pounds phosphoric acid 67 pounds potash	52.2	15.2	67.4	37	38.6	6	6 13	47 84	62 20	35 53	4,800	71
33	186 pounds dissolved bone-black 64 pounds muriate potash 320 pounds sulphate ammonia	31 pounds phosphoric acid 33½ pounds potash 64 pounds nitrogen	38.8	14	52.8	......	24	......	19 89	36 64	48 04	21 37	3,800	74
34	Nothing		12.4	12.8	25.2	......	......	......	......	15 04	25 54	......	3,500	138
35	180 pounds dissolved bone-black 320 pounds sulphate ammonia	31 pounds phosphoric acid 64 pounds nitrogen	No	yield	pract	ically.	......	......	18 45	......	2 10	Loss. 2 57	700	......
36	93 pounds dissolved bone-black 128 pounds muriate potash 320 pounds sulphate ammonia	15½ pounds phosphoric acid 67 pounds potash 64 pounds nitrogen	13.6	17.1	30.7	......	1.9	......	19 71	17 72	25 52	Loss. 1 15	2,600	84
38	128 pounds muriate potash 320 pounds sulphate ammonia	67 pounds potash 64 pounds nitrogen	14.5	19.7	34.2	......	5.4	24.5	18 08	25 28	38 18	11 51	4,300	122
39	186 pounds dissolved bone-black	31 pounds phosphoric acid	15	18.1	33.1	55.5	4.3	4.5	3 25	19 24	29 44	2 77	3,400	102
40	Nothing		20.2	13.8	34	35	5.2	......	......	21 68	32 78	6 11	3,700	109
41	128 pounds muriate potash	67 pounds potash	47.3	16.6	63.9	59.5	35.1	28	2 88	44 48	56 48	29 61	4,000	62
42	320 pounds sulphate ammonia	64 pounds nitrogen	15	16.9	31.9	36.2	3.1	5.2	15 20	18 76	37 06	10 30	6,100	191
44	16 tons yard manure	Estimated to contain twice material, plot 28	90.1	9	99.1	62.8	70.3	31.3	28 00	72 44	185 44	78 77	11,000	111
44½	Nothing		8.7	16.2	24.9	......	......	......	......	13 44	20 88	......	2,480	99
48	160 pounds magnesia 80 pounds salt 120 pounds lime	——phosphoric acid 33.6 pounds potash 74.2 pounds nitrogen	8.7	12.5	21.2	43.8	Loss. 7.6	......	......	11 96	20 78	Loss. 5 89	2,940	134
49	1,000 pounds decorticated cotton-seed meal		35.3	14.1	49.4	......	20.6	......	16 00	33 88	54 58	27 91	6,900	139
51	Nothing		1.83	12.8	31.1	31	......	......	......	19 76	27 56	......	3,600	115
54	40 bushels ashes		4.09	9.9	50.8	38	22.0	7	10 00	36 68	55 28	29 61	6,200	121

Mr. Sanborn comments upon these results as follows:

One of the most striking and important results brought out by the table is the relation of the ammonia salts to the crop, and its contrast to results of last season. Last year an increasing quantity of ammonia salts gave an increasing crop up to the largest amount used in plot 28; and everywhere where used, on all plots, both to corn and potatoes, in connection with minerals, gave a large increase of crop for its use, and a profit for use up to three-fourths formula, or amount used in plot 29, notwithstanding its very high cost. This season wherever used it brings a loss, excepting a very slight gain for one-fourth part as in plot 31 over 32, but not a profitable gain. Plot 42 gives, it is true, a little more than the average of the nothing plots, but not so much as plot 40 near to it. And I may add here as a very interesting fact, apparently, that plots 40 and 31 represent probably the true native fertility of the soil for the season better than 34 or 44½; for 34 and 44½ were fallow for the season of 1878, while the others bore heavy crops for unmanured land. I have other facts that in a future paper I shall allude to, that go strongly to show that the bare fallow was, at least so far as this season's crop is concerned, an injury. If my conclusions are right, the experimental land is of rarely uniform fertility. The two bare fallowed last year agreeing nearly in crop, and the other two that bore a crop corresponding very close in yield. The plots run in rows of nine, parallel to each other, thus the nothing plots are well interspersed among the fertilized plots

But to return to the ammonia plots. I observed that the stalks were not so vigorous as those to minerals alone, or minerals and a slight quantity of ammonia salts, and were, as my record shows, an easy prey to worms. Why this result? Is it due to the quality of the ammonia? No; because the minerals alone gave as good crop as could have been expected had the ammonia salts been added with complete success as in plots 41 and 54 and 32. In 32 only potash salts were used to give theoretically 43 bushels of increase of crop of corn, yet without any ammonia 38.6 bushels of increase was made. Now the same plot gave but 6 bushels increase over nothing plot last year. So of ashes and other mineral plots; they gave but little or no increase both on corn and potatoes over nothing plots, while this year they give as good results as last year when ammonia salts were profitably used. Neither was it due to ammonia salts left over in the soil; for the mineral plots had no ammonia salts, and in case of those plots that did have a liberal use of them the increase of crop was so heavy as to absorb nearly all of these salts. Nor is it due to any carelessness of mine, or to a local influence; for I put out several experimental sets and in different sections of the State and on diverse soils, and the results come to me the same. I would call particular attention to this point, because no question in fertilization is at once so difficult and important to fathom. Last year, in round numbers, $12 worth of ammonia salts paid a profit for use. This year they are worse than useless, and are over one-half of the cost of fertilization for an acre of corn; yet had they not been used last season but little increase of crop (6 bushels) would have been harvested. I can only say that I believe that the character of the season has more to do with the ability of a plant to gather its nitrogen from natural sources than has been generally recognized, and that at present science does not explain it fully, nor can we at present combine fertilizers for seasons. We may, however, accept the averages of several seasons as the safest mean. It would appear to me to be prudent for the time to use about one-half of what has become to be known as full formula of nitrogen for corn. By comparatively recent experiments of Berthelot and others, it appears that the electrical condition of the atmosphere has much to do with the power of a plant to gather its nitrogen nourishment from the natural source, from the air, and that that condition is quite variable in different seasons and in the same season.

POTASH THE MANURE OF THE CROP.

It will be noticed, on comparison of plots, that the presence or absence of potash

affects the crop more than either of the other materials. This same result has been noticed here for the three years of my observation, both on the plot work and in the main field. The fertilizers ordinarily put upon the market containing no potash would thus be of little use on this farm, and this is the experience of my neighbors up and down the river on land of the character of this farm. I respectfully suggest that if they would use potash salts with superphosphates, more satisfactory results would probably be obtained.

These experiments have continued through four seasons, from 1878 to 1881. No detailed account of the whole has as yet been published. Mr. Sanborn has, however, kindly favored me with a brief summary of results of the four years in the following form:

I take it that you simply desire a statistical statement of crop returns from the nitrogen plots alone, and this I give you in brief tables.

Experiments on effects of nitrogenous and other fertilizers upon corn in 1878, 1879, 1880, and 1881.

BY MR. J. W. SANBORN, *New Hampshire Agricultural College.*

SHELLED CORN.

Number of plot.	Fertilizers per acre.		Yield per acre in bushels, stalks in pounds.															
			1878.				1879.				1880.				1881.			
	Materials.	Ingredients.	Sound.	Soft.	Total.	Stalks.	Sound.	Soft.	Total.	Stalks.	Sound.	Soft.	Total.	Stalks.	Sound.	Soft.	Total	Stalks.
28	320 pounds sulph. of ammonia 186 pounds dis. bone black 128 pounds mur. of potash	64 pounds nitrogen 36 pounds phos. acid 77 pounds potash	66.5	2.5	69.0	5,480	29.4	16.4	45.8	5,400	7.8	1.5	9.4	2,060	16.5	5.8	22.5	4,000
*29	240 pounds sulph. of ammonia 186 pounds dis. bone black 128 poundsmur. of potash	48 pounds nitrogen 31 pounds phos. acid 77 pounds potash	60.0	5.0	65.0	5,320	44.7	16.4	61.1	6,640	16.1	4.1	20.2	2,940	25.5	5.7	31.3	4,967
30	160 pounds sulp. of ammonia 186 pounds dis. bone black 128 pounds mur. of potash	32 pounds nitrogen 31 pounds phos. acid 77 pounds potash	48.5	5.0	53.5	4,200	50.6	14.0	64.6	6,200	15.6	6.5	22.1	2,940	29.8	5.8	35.5	4,300
31	80 pounds sulp. of ammonia 186 pounds dis. bone black. 128 pounds mur. of potash	16 pounds nitrogen 31 pounds phos. acid 77 pounds potash	44.0	4.0	48.0	4,340	55.5	13.5	69.0	6,300	29.4	2.1	31.5	3,100	36.0	5.0	41.0	4,460
32	186 pounds dis. bone black 128 pounds mur. of potash	31 pounds phos. acid 77 pounds potash	33.8	3.2	37.0	2,640	52.5	15.2	67.7	4,800	28.2	3.8	32.0	2,740	†30.4	4.7	34.8	3,700
34	Nothing	......	33.8	......	......	......	12.4	12.8	25.2	3,500	0.0	3.2	......	1,040	1.8	5.1	67.8	2,400
35	186 pounds dis. bone black 320 pounds sulp. of ammonia	31 pounds phos. acid 64 pounds nitrogen	......	......	......	......	worthless.			....	0.0	1.0	......	380	0.0	1.8	......	700
38	128 pounds mur. of potash 320 sulph. of ammonia	77 pounds potash 64 pounds nitrogen	53.8	1.8	55.5	4,160	1.5	11.5	26.5	3,400	5.2	1.9	7.1	1,700	22.0	8.2	28.2	2,900
40	Nothing	......	......	......	40	......	......	......	......	......	4.3	3.2	7.5	1,300	3.0	8.0	8.0	2,000
42	320 pounds sulph, of ammonia	64 pounds nitrogen	57.8	1.8	58.5	2,420	20.2	13.8	34.0	3,700	1.7	1.5	3.2	600	0.0	2.5	2.5	800
54	30 to 40 bu. ashes	......	......	......	38.0	4,460	40.9	9.9	50.8	6,200	31.1	2.3	33.4	2,840	47.2	3.8	81.0	4,000

* It was found after the experiments were started that in the distant past charcoal had been burned on plot 29. The fourth year 300 pounds dis. bone black was used The fourth year and third year 240 and 160 pounds of muriate of potash were used respectively.

† Plot 32 was injured by some cause. If the hills had been complete it would have been as good as 31.

Experiments on effects of nitrogenous and other fertilizers upon potatoes in 1878, 1879, 1880, and 1881.

BY MR. J. W. SANBORN, *New Hampshire Agricultural College.*

Number of plot.	Fertilizers per acre.		Yield per acre in bushels. 1878. Marketable.	1878. Small.	1878. Total.	1879. Marketable.	1879. Small.	1879. Total.	1880. Marketable.	1880. Small.	1880. Total.	1881. Marketable.	1881. Small.	1881. Total.
1	105 pounds sulphate of ammonia, mineral manures*	21 pounds nitrogen; 11 to 15 pounds phosphoric acid; 34 to 60 pounds potash	122.5	83.5	206.0	96.0	48.0	144.0	85.3	63.9	149.2	15.3	32.0	47.3
2	Nothing		39.0	83.6	122.6	6.0	50.3	56.3	7.5	58.6	66.1	......	15.6	15.6
3	52½ pounds sulphate of ammonia, mineral manures*	10.5 pounds nitrogen minerals*	115.6	76.6	192.2	95.0	46.6	171.6	62.6	69.5	132.1	20.3	22.3	42.6
4	Mineral manures		101.0	73.6	174.6	107.6	49.0	156.6	76.6	71.3	147.9	22.5	22.0	44.5
6	105 pounds sulphate of ammonia, potash salt	21 pounds nitrogen potash*	129.0	69.3	198.3	70.3	57.3	127.6	80.3	74.3	154.6	19.0	30.3	49.3
10	105 pounds sulphate of ammonia, superphosphate*	21 pounds nitrogen phosphoric acid.	62.5	58.4	120.9	23.6	37.6	61.3	24.5	61.6	86.1	7.3	21.5	28.8
12	105 pounds sulphate of ammonia	21 pounds nitrogen	80.3	80.4	164.3	47.0	47.0	94.0	40.7	55.3	96.0	8.3	20.8	29.1

* Superphosphate and potash salt as in corn experiment. (See preceding table).

The results of the use of ammonia for corn are a source of inexplicable astonishment to me. Various reasons have suggested themselves to me, but each fail to account for the results. It is known that sulphate of ammonia is sometimes in its production accompanied with injurious matter or matters. I doubt if this accounts for the results, as I do not note it in the potatoes. It is noteworthy that the ashes are steadily increasing the crop, although they contain no nitrogen, and last season was unfavorable.

I may say that on the plots with large rations of nitrogen, the corn starts well, looks healthy for awhile, but gradually it turns to a sickly color, and in many cases dies out completely. On the plot with nitrogen alone in 1881, nearly all of the corn was alive in August, but gradually disappeared, so that before harvest it was mostly gone.

The coming season I propose to investigate this matter of the injurious effect of nitrogen.

Regarding the results with the potatoes I have no comments to make other than that the unreported plots that received no nitrogen, when compared with those that have nitrogen, puzzled me for awhile. I now find it clear that the sulphuric acid of the bone black and sulphate of ammonia have affected the results favorably, and that whatever gain comes from the use of either superphosphate or sulphate of ammonia is due wholly to the sulphuric acid they contain.

Mr. Sanborn's experiments seem to me among the most interesting I have seen. That the soil should have proven so uniform, as shown by the agreement of the results on the unmanured plots, even when the plots were in checks rather than in long, narrow strips, is most fortunate.

That sulphate of ammonia should so materially benefit the corn the first season, injure it the second, and, in succeding years, almost destroy it, is certainly very strange. The increase of the yield year after year with ashes is likewise remarkable. All these phenomena demand careful and thorough investigation.

It is perhaps worthy of note in this connection that the experiment of Colonel Mead, of Vermont (see Appendix, Table I), in which nitrogen proved injurious rather than helpful to the corn while potash was so beneficial, was not very far from Hanover, N. H., where Mr. Sanborn's experiments were made.

Mr. Sanborn informs me that he has made arrangements to bring his experiments as nearly as possible into accord with the co-operative plan followed by the experimenter whose work has been set forth in Tables I–III, appendix.

In the language above quoted and elsewhere, Mr. Sanborn strongly urges the importance of the study of the demands of soil and crop by experiment. In connection (I believe) with the New Hampshire board of agriculture, the agricultural college, through Mr. Sanborn, has induced farmers in various parts of the State to institute trials with fertilizers containing nitrogen, phosphoric acid, potash, &c., similar to the "general experiments," described in the earlier part of this article. The results, so far as published, amply justify Mr. Sanborn's recommendations and conclusions.

EXPERIMENTS AT THE UNIVERSITY OF TENNESSEE BY PROFESSOR M'BRYDE.

Prof. J. M. McBryde, ot the University of Tennessee, at Knoxville, has lately reported a series of experiments analagous to those described above and with similar purpose, though the questions studied are much more numerous.*

In view of the publicity already given to these experiments, and the lack of space here, I refrain from quoting the details.

The results of Professor McBryde's experiments, however, accord with the general impression which makes nitrogen the most efficient of the fertilizing elements in promoting the growth of wheat. From the strictly practical stand-point also, they are of interest in illustrating how the use of concentrated fertilizers often brings more of loss than gain. Unfortunately the differences in produce of the different plots is, as Professor McBryde urges, hardly great enough to exceed the limits of error due to inequalities of soil, and with so few duplicate tests the results will hardly warrant generalizations even for the conditions in which the trials were made.

Such extensive and painstaking investigations are, nevertheless, of great value, and will become increasingly so as they are continued from year to year.

GENERAL DISCUSSION OF RESULTS OF THE EXPERIMENTS.

THE FEEDING CAPACITIES OF PLANTS.

The experiments we are discussing bring us face to face with one of the most important problems with which agricultural chemistry has to deal, and, at the same time, throw some new light upon it. I refer to what may perhaps be called their feeding capacities, their power of gathering their supplies of food from soil and air, and the effects of the different ingredients of plant food upon their growth.

A vast deal of experience in the laboratory and in the field bear testimony to the fact, though we are still deplorably in the dark, as to how or why it is so, that different plants have different capacities for making use of the stores of food that soil and air contain. Thus experience and experiments tell us that clover and, perhaps, leguminous plants generally do somehow or other succeed in obtaining a sufficient supply of nitrogen, where cereals, such as wheat, barley, rye, and oats would half starve for want of it, and this in the face of the fact that leguminous plants contain a great deal of nitrogen and the cereals relatively little. Hence a heavy nitrogenous manuring may be profitable for wheat and be in large part lost on clover.

* Experimental work of the Agricultural Department of the University of Tennesse 1881. A portion of the same report, also given in an article by the same author, entitled "Chemical Manures on Wheat," in the Agricultural Review, January, 1882, page 75.

As long ago as 1850, Dr. Pusey said in a report "On the progress of agricultural knowledge during the last eight years," in the Journal of the Royal Agricultural Society (vol. xi. 1850, pp. 385–6), "At present we can only say that the three leading principles of manure are: 1, Ammonia; 2, Phosphorus; and, probably 3, Carbon;" and again, "The upshot of the whole is that practically, as far as artificial manures are concerned, we need not dwell upon the mineral ingredients, but must give ammonia to wheat, and to turnips phosphorus." Since Dr. Pusey's time we have got hold of very many new facts, theories of manuring have multiplied, and fertilizers for special crops, based upon various theories, have come into very general use.

The little definite knowledge we have of the different feeding capacities of plants comes in part from general observation and in part from direct experiment.

The experimental data have been contributed by various investigators, especially by Messrs. Lawes and Gilbert, of England, whose classic researches on the fields and in the laboratory at Rothamsted are familiar to all students of agricultural science.

Next in prominence, perhaps, in this field of discussion is M. Georges Ville, of France, whose experiments, however, do not compare in extent with those of Messrs. Lawes and Gilbert, but whose theories are much more numerous and definite.

How it is, by virtue of what characteristics, organs, or functions of different plants they possess these different capacities for gathering their food are questions still to be solved. Sir John Lawes, in an article on fertility, with which many of the readers of this are familiar, in discussing the relations of different plants to the nitrogen supply, says:

> It is not to the difference of their capacity for taking nitrogen from the atmosphere that we must look for an explanation of the distinctive influence, or function, so to speak, of the crops grown in a rotation. The explanation is rather to be found in the difference in the character and length of life of the different plants, in the character of the roots in regard to number, range, size, and to their aptitude to derive more of their food and moisture from the surface, or from the subsoil, and finally, in the greater capacity of some for liberating and assimilating food not available to others, or for arresting food which would otherwise be washed out of the soil. * * *
>
> If we consider the well-established characteristics of the various leguminous crops grown in rotation, and the circumstances of their growth, it will be seen that their powers of taking up nitrogen and of contributing to the increased growth of succeeding crops are much in proportion to the length of their lives and the range of their roots. Thus every one will admit that lucern, sainfoin, and red clover will grow larger crops without manure, and will leave a larger residue for the growth of succeeding crops, than either white clover or tares.
>
> Again, if we follow the course of a barley and of a red-clover crop, both sown nearly at the same time, it will be seen that when the barley has ripened its seed the active growth of the clover has scarcely commenced, and the plant has still the latter part of the summer, the whole of the autumn, and to the autumn of the succeeding year to collect its food. A man would consider himself very unfairly handicapped if he were required to do as much work in four months as another was allowed eighteen months in which to perform it. After the cessation of the life of the barley, the formation of

nitric acid in the soil is doubtless still active. In fact direct experiments show that the autumn drainage removes more nitrates than that of other periods of the year.

It is doubtless one of the economic functions of the clover plant to arrest and store up the nitrogen of the nitric acid in the soil which would otherwise be drained away during the autumn and winter. Whether or not the leguminosæ may further take up any of their nitrogen directly from the nitrogenous organic matter within the soil there is no direct evidence to show, though there are some facts which might be held to lend probability to the assumption.

When we see that the appearance of a fungus, even on very poor grass land, is always accompanied by a rich growth of grass, we conclude that it has the property of liberating and utilizing nitrogenous compounds in the soil which the grasses were unable of themselves to turn to account. It is, at any rate, not impossible that the leguminosæ may likewise derive at least a portion of their nitrogen from the nitrogenous organic compounds within the soil; but their possession of green leaves may be taken as evidence that they derive the chief of their carbon from other sources than the organic carbon of the soil.

The above remarks are made by their author in a discussion of the question whether plants obtain any considerable quantity of their nitrogen from the air—a question which he is inclined to answer quite decidedly in the negative. They seem to me, however, to apply very aptly to the more general problem of the capacities of plants.

If the superior faculty of clover, as compared with wheat, for accumulating nitrogen be due to its larger amount of root surface, and its longer period in which this gathering is done, why may it not for the same reasons be better able than wheat to obtain its phosphoric acid, potash, and other food ingredients? Indeed, why may not any characteristic which gives clover an especial ability to gather its nitrogen be equally efficient as regards the lime, or phosphoric acid, or potash? The point seems to me to lie here: Plants differ in these respects. Why they differ, we may surmise, but cannot affirm. What we need to do is to find out: and the experimental data needed are to be sought partly in the greenhouse and partly in the field.

THE VILLE THEORIES OF FERTILIZATION.

Of the various theories of fertilization perhaps no others have attracted so much attention as those of Professor Ville, whose experiments on the government farm at Vincennes during more than a quarter of a century have been discussed, and whose writings are read the world over. The prominence which the doctrines of Ville have obtained in the agricultural press, and among farmers in this country, coupled with the marked discrepancy between them and the results of the large number of experiments here detailed, seems to warrant at least a brief discussion of the theory.

One of the essential features of Ville's doctrine is the theory of dominant ingredients. He gives "the name *dominant* to the ingredient which, for a given crop, plays a more important part than the others." Thus:

Nitrogen is the predominant ingredient for the cereals, as wheat, barley, rye, oats, and for colza, sugar-beet, hemp, &c.

Potash has an especial influence upon peas, beans, clover, lucern, flax, potatoes, &c.

Phosphoric acid is especially beneficial for turnips. rutabagas, radishes, Indian corn, sugar cane, &c.

Lime seems to exert no especial preponderating action upon any plant, but is necessary for all.

Of the numerous ingredients of fertilizers Ville regards the four named, nitrogen, phosphate of lime (phosphoric acid), potash, and lime, as the regulators *par excellence* of production, and the only ones with which agricultural industry need occupy itself. His formulas for "complete manures" supply these four ingredients—the *nitrogen* as nitrate of potash (saltpeter), nitrate of soda, or sulphate of ammonia; the *phosphoric acid* in the form of superphosphate; the *potash*, in either nitrate of potash, or other potash salts, and the *lime* as sulphate of lime (land plaster). He says that "the mixture of these substances has the same properties as dung." The "complete chemical manure is to the barn-yard manure what the metal is to the ore." "It is farm-yard manure divested of all useless matter."

The practical inference is that in preparing a fertilizer for a given plant, we must reduce the subordinate ingredients as much as we can, and put in a good deal of the dominant. To sustain his propositions, Ville cites a great many experiments, some made by himself in pots or in the fields of the experimental farm at Vincennes, and others by farmers in France and elsewhere. In an experiment on wheat, for instance, one plot received a "complete manure;" from another the lime (sulphate of lime) was omitted, while the third had no potash, &c.

Fertilizer.	Yield of wheat per acre.
	Bushels.
Nothing	15.88
"Complete manure"	56.44
"Complete manure," without lime	53.33
"Complete manure," without potash	40.44
"Complete manure" without phosphoric acid	34.66
"Complete manure," without nitrogen	18.18

The wheat suffered more from lack of nitrogen than from lack of any other ingredient. Again, with sugar-beets, starting with a complete fertilizer which supplied 360 pounds of superphosphate, 180 pounds of nitrate of potash, 270 pounds of nitrate of soda, and 360 pounds of sulphate of lime per acre, when more lime, potash, or phosphoric acid was added, the yield was not affected, but when the nitrogen was increased the yield rose with it. From such experiments as these, Ville infers that nitrogen is the dominant ingredient for wheat and the sugar-beet, and consequently he puts a large proportion of it in his formulas for these crops. He insists, furthermore, that the form of combination is important, and uses sulphate of ammonia for wheat, nitrate of soda for

sugar-beets, and so on. For clover, beans, peas, &c., he recommends little or no nitrogen, because the plants are found to get very little if any good from nitrogenous manures. He explains this by assuming that such plants get all their nitrogen from the air, and do not need it in fertilizers. Of the theory once held by many that plants assimilate the free nitrogen of the air, Ville has been for some years almost the only prominent defender. He claims that clover gathers all its nitrogen from the air; that barley and rye get 80 per cent., wheat 50 per cent., and sugar-beet, 60 per cent. from the air, and the rest from the soil.

Concerning the mineral ingredients, phosphoric acid, potash, and lime, Ville's rule is to restore all that the crops remove, and a little more to make up for what is leached away by water in the soil below, beyond the reach of the roots of plants; thus strangely ignoring the resupply which every soil keeps up from the decomposition of its material.

COMPLETE OR NORMAL MANURES.

The formulas for chemical manures are one of the chief features of Ville's system. He sums up his doctrine of chemical manures as follows:

No. 1. The complete chemical manure embraces all the fertilizing principles of dung, all of whose active portion it contains, and to which it is superior in the harvests it brings.

No. 2. For the action of each one of the four substances of which the complete manure is composed (viz., phosphoric acid, potash, lime, and nitrogenous material), the co-operation of the three others is necessary.

No. 3. Each one of the four terms of the complete manure has a function subordinate or preponderant with respect to the other three, according to the nature of the plants. [The principle of dominants as above explained.]

No. 4. Analysis of the soil by culture.

That is, the testing of soils by experiments with different fertilizing materials, in order to find whether any are supplied in sufficient quantity by the soils, and may consequently be omitted from the fertilizers. Ville lays great stress upon these experiments and gives very full directions for conducting them.

CHEMICAL FERTILIZERS SUPERIOR TO FARM MANURES.

Ville claims that chemical fertilizers are superior to farm manures for several reasons:

(1.) They bring larger crops. In proof of this he cites several hundred experiments made by agricultural schools, societies, and private individuals, on wheat, oats, rye, barley, maize, potatoes, sugar-beets, sugar-cane, &c., in France, Belgium, Germany, Italy, and other countries. In fifty-one experiments with wheat, in which chemical and farm manures were compared, the chemicals brought larger crops in forty-seven, less in three, and the same in one case. In ninety-two experiments with sugar-beets the artificial fertilizers brought the best results in sixty-seven cases, the dung in twenty cases, and both the same in five cases. In thirty-two experiments with potatoes, the chemical manures brought more than horse-manure in twenty-five, less in six, and the same in one.

(2.) The chemical fertilizers are cheaper. To substantiate this he makes extended comparisons between the cost in France of farm manure and the corresponding chemical materials, and calculates that the manure is the dearer by some 6 per cent.

(3.) Chemicals are always at command, and in just such kinds and quantities as are needed, the only limit being the amount of capital to be invested.

(4.) The ingredients of chemical manures are ready for use at once, while in yard-manure they are slowly available.

(5.) Chemical manures are more easily and cheaply transported, handled, and applied.

(6.) Chemical manures can be divided so as to use for each crop its predominant regulating ingredient, and in each case only what is needed. Thus, in a rotation, nitrogen can be used for wheat or oats, phosphates for corn or turnips, and potash for clover. Or, if the soil supplies enough of any one ingredient for any crop, it can be omitted from the fertilizer and its cost saved.

CONTINUOUS USE OF CHEMICAL MANURES.

To the question whether chemical manures alone can be depended on and used with profit year after year, Ville replies:

Yes, under two conditions: 1st. Give the land in fertilizers more phosphate of lime, more lime, and more potash than the crop takes from it. 2d. Give it about 50 per cent. of the nitrogen of the harvest.

Ville says, very aptly:

The employment of chemical manures requires especial care. Like fine weapons, they show a full measure of their power only in hands that understand how to use them.

VILLE'S FORMULAS.

The following are some of Ville's principal formulas. The amounts are calculated per acre. In changing French weights into ours fractions are avoided. The costs are estimated at rates current in our large markets:

WHEAT.

Complete manure No. 1. [*Dominant, nitrogen.*]

Fertilizers.	Quantity.	Ingredients.	Quantity.	Cost.
	Pounds.		*Pounds.*	
Acid phosphate of lime	360	Phosphoric acid	54	\$6 30
Nitrate of potash	180	Potash Nitrogen	79 23	16 20
Sulphate of ammonia	225	Nitrogen	23	1 20
Total	*1,080			*33 88

* The author has made an omission in this table, as will be seen from the additions.

BARLEY, RYE, OATS, AND GRASS.

Complete manure No. 1. [*Dominant, nitrogen.*]

Only one-half of above amounts.

BEETS, CARROTS, GARDEN VEGETABLES, ETC.

Complete manure No. 2. [*Dominant, nitrogen.*]

Fertilizers.	Quantity.	Ingredients.	Quantity.	Cost.
	Pounds.		*Pounds.*	
Acid phosphate of lime	360	Phosphoric acid	54	$6 30
Nitrate of potash	180	Potash	79	16 20
		Nitrogen	23	
Nitrate of soda	270	Nitrogen	42	10 80
Sulphate of lime	270			1 08
Total	1,080			34 38

POTATOES.

Complete manure No. 3. [*Dominant, nitrogen.*]

Fertilizers.	Quantity.	Ingredients.	Quantity.	Cost.
	Pounds.		*Pounds.*	
Acid phosphate of lime	360	Phosphoric acid	54	$6 30
Nitrate of potash	270	Potash	119	24 30
		Nitrogen	35	
Sulphate of lime	270			1 08
Total	900			31 68

For worn-out soils complete manure No. 2 is preferable.

TURNIPS, RUTABAGAS, SORGHUM, SUGAR CANE, CORN (MAIZE).

Complete manure No. 5. [*Dominant, phosphoric acid.*]

Fertilizers.	Quantity.	Ingredients.	Quantity.	Cost.
	Pounds.		*Pounds.*	
Acid phosphate of lime	540	Phosphoric acid	81	$9 45
Nitrate of potash	180	Potash	79	16 20
		Nitrogen	24	
Sulphate of lime	360			1 44
Total	1,080			27 09

BEANS, PEASE, CLOVER, ETC.

Incomplete manure No. 2. [*Dominant, potash.*]

Fertilizers.		Ingredients.	Quantity.	Cost.
	Pounds.		*Pounds.*	
Acid phosphate of lime	360	Phosphoric acid	54	$6 30
Nitrate of potash	180	Potash	79	16 20
		Nitrogen	24	
Sulphate of lime	360			1 44
Total	900			23 94

This is "incomplete," in that part of the nitrogen (of No. 2) is omitted. As Ville assumes that the above plants get all their nitrogen from the air, he explains that the nitrate of potash is put in here for the sake of the potash, and that the small amount of nitrogen can do no harm.

THE EXPERIMENTS OF MESSRS. LAWES AND GILBERT.

By far the most valuable contribution to our knowledge of these subjects comes from the field experiments of Messrs. Lawes and Gilbert. In their experiments, wheat, which has for thirty years received mineral manures alone, has averaged $16\frac{3}{4}$ bushels per acre yearly, against 14 bushels unmanured. The addition of sulphate of ammonia, with the same repeated cropping of the same land, brought the average up to 36 bushels per acre. The leguminous crops have told just the opposite story. Though they contain a good deal more nitrogen than wheat, they respond but slightly to nitrogen, and are greatly aided by mineral manures. In an experiment on the mixed herbage of grass-land, continued through twenty years, mineral manures without potash brought up the total crop 47 per cent., and the nitrogen in the crop 38 pounds per acre annually above the unmanured. And when potash was added to the mineral manures the crop was 67 per cent. larger, and contained 56 pounds more nitrogen per acre than the unmanured, the increase in nitrogen being in large measure due to the leguminous plants, which came in under the influence of the potash and replaced plants of other families.

In one case Messrs. Lawes and Gilbert found that a soil from which a clover crop had just been removed contained more nitrogen than it did before the clover was put in; that, in other words, the soil to a depth of 9 inches at least was positively enriched by the growth and removal of a highly nitrogenous (clover) crop.

Such facts help to explain why it is such good farm-practice to use mineral fertilizers, as plaster, bone, ashes, and potash salts, for mixed grasses and clover, and nitrogenous materials, like guano, sulphate of ammonia, and nitrate of soda, for grain crops. They help us to understand why clover is such an excellent preparatory crop for wheat, and so economical generally for plowing under to bring up poor soils. It gathers and stores plant-food, particularly nitrogen, and thus is itself a fertilizer.

In Messrs. Lawes and Gilbert's experiments the cereals have been most helped by nitrogen, next by phosphates, and very little by potash. The legumes have responded to mineral manures, especially potash, and paid little heed to nitrogen except where on meadow land they have, under the influence of nitrogenous manuring, gradually run out and the grasses have taken their place, just as they have replaced the grasses when mineral manures alone were used. Turnips have done best with superphosphates; and potatoes, I think, have seemed to demand potash, along with nitrogen and phosphates, for their best development.

For some time past the relation of the corn-plant to the nitrogen supply has been a much-vexed question. The main question is whether, like other cereals (wheat, barley, oats, grasses, &c.), corn has but little power to gather nitrogen from natural sources and requires nitroge-

nous fertilizers, or whether, like the legumes, corn can gather nitrogen for itself. In short, whether corn is, like wheat, an exhausting crop, or, like clover, a renovating crop. Sir John Lawes is, or at least has been, inclined to class maize with the cereals, wheat, oats, &c., because they belong to the same botanical family, but at the same time urges the need of experiements to test the question. Trials on his own farm have failed because in the cool English climate the corn did not mature. In a letter to the New Jersey State Board of Agriculture,* he says:

It is of very great importance to know to what extent Indian corn follows the same law [as the cereals]; that is to say, on a soil which will, under a liberal supply of potash and phosphoric acid, yield 20, 30, or 40 bushels of corn, what increase is obtained by a liberal supply of ammonia and nitrates.

In a letter to Mr. Harris, Mr. Lawes discusses this question in a manner which seems to me worthy of quotation here, although it has appeared in print before.† I select the paragraphs bearing especially upon the topic in question:

There seems to be some doubt in the minds of yourself and farmers generally in the United States with regard to this important crop, maize or Indian corn. You are divided in your opinion whether it should rank as a cereal or a leguminous crop. I do not, of course, mean that you question its botanical position, but you say, "In its capacity to obtain manure from the soil, it resembles a leguminous rather than a cereal crop." Your argument is this: Take a field in equal condition, divide it into two portions, sow maize on one-half and wheat on the other, and you will obtain say 30 bushels per acre of maize and 15 of wheat.

The average yield of maize in the States for ten years is 26 bushels per acre; of wheat, 12 bushels. This shows rather more than twice as much maize as wheat, and as maize generally precedes wheat in ordinary farming, and consequently has some advantage in regard to the condition of the land, we may accept your figures, and say that with equal condition of soil the produce of maize will be double that of wheat. How is this to be explained?

As an unfavorable climate has prevented me from experimenting in maize, the remarks I am about to make must be accepted as suggestions to elicit thought in others, rather than as opinions of my own, upon which too much confidence should not be placed. Maize belongs to the great family of graminaceæ, which supply the food of almost the whole of the human race. Botany, in advance of chemistry, settled the natural order; later on, chemistry, by showing that all the plants in their natural order resembled each other in their chemical composition, confirmed the arrangement. The large amount of silica which is found in the ash of the maize proves that it has no connection with a leguminous plant; it may also be distinguished from the latter plant by the low amount of nitrogen and large amount of starch which its seed contains.

This, however, does not explain why it can appropriate so much more food from the soil and atmosphere than the wheat plant. Assuming that maize and wheat live upon the same soil food, which I am quite disposed to think is the case, we must not lose sight of the capacity of one plant, as compared with another, of collecting and assimilating food. Even in two different varieties of the same species of plant this property is shown in a very distinct manner. * * *

It is possible that maize may, from its vigorous habits of growth, possess a

* Fourth Annual Report of the New Jersey State Board of Agriculture, 1876, 39.

† In the American Cultivator, and in part in the account of Field Experiments with Fertilizers, in the Reports of the Connecticut Board of Agriculture for 1878–'80.

greater capacity for taking up food from the soil than the wheat, but maize has other distinctive properties which require to be noticed. Compared with wheat, the active life of maize extends far longer into summer and autumn. In the south of France, maize sown in the beginning of May is ripe at the end of October; in the same locality wheat is ripe in July. The most active growth of maize takes place after the wheat has ceased to collect its food. During the summer and autumn nitric acid is largely formed in the soil, and is taken up by both wheat and maize; but the early ripening of the wheat stops further collection by that plant, while maize continues to collect until late in the autumn. The formation of nitric acid goes on in the soil after the wheat is removed, but much of this is washed out of the soil by the winter rains. We see, therefore, that maize, by its habits of growth, has access to more nitrogen, in the form of nitric acid, than wheat.

And we have, also, in this fact an explanation of the action of mineral manures. Superphosphate is said, by you, to be a better manure for maize than for wheat; both require phosphates and nitrogen, but the maize gets more nitrogen, and, consequently can take up more phosphate. In all soils exhausted by corn crops, you may predict with certainty that ammonia or nitric acid applied as manure will increase a wheat crop, there being a large balance of mineral food which cannot be taken up by the wheat in the absence of nitrogen.

One other point may be noticed. Maize contains a smaller amount of nitrogen than wheat; I have seen analyses which only showed one-half as much; probably one-fourth less would be nearer the average. Taking all these matters into consideration, if wheat and maize were grown continuously for experiment, I should expect that maize, if manured with manure such as wood ashes and superphosphate, would give a larger produce than wheat. But to produce full crops, both would require, in addition, large quantities of nitrogen to be supplied as ammonia or nitric acid.

In brief, Mr. Lawes would expect that corn, during its longer period of growth, would, with the aid of mineral fertilizers, produce a larger yield, and, of course, gather more nitrogen than a wheat crop; but he is at the same time inclined to class it with the cereals.

SPECIFIC EFFECTS OF THE DIFFERENT FERTILIZING MATERIALS.

As a means of studying the effects of the nitrogen, phosphoric acid, potash, and so on, we have prepared some tables, which we have got in the way of calling "tables of difference": Tables X and XI of the Appendix. These show very clearly the effect of each material—nitrate of soda, superphosphate, and muriate of potash—both when used alone and when mixed with the others; and also presents in a very clear light the uniformity or irregularity of the action of each one on the different plots of each experiment. For instance, the effect of nitrate of soda alone is found by subtracting the average yield with no manure from that of the nitrate of soda plot. To find its effect with superphosphate, the yield of the phosphoric acid plot is subtracted from that which had the mixture of the two. The increase with the complete fertilizer over that with the superphosphate and potash salt, gives the effect of the nitrate of soda again, and so on. Of course it is understood that these differences in a given case do not express exactly the effect of the nitrogen, phosphoric acid, or potash, nor even that of the fertilizer containing them. The indirect action of the fertilizer counts for something, and the irregularities in the different plots often a good deal more.

It would be wrong to assume, in the case of superphosphate for instance, that its effect was due exclusively to its phosphoric acid, since it contains also sulphuric acid and lime, which at times may be very effective.

It is to be noted, also, that the quantities of nitrogen, phosphoric acid, and potash are not the same, so that the figures should be understood as applying to the quantities actually used.

It will be noted that Table X contains, also, a column showing the effects of sulphuric acid and lime together in plaster. Bearing this consideration in mind, it will, for our present purpose, suffice to treat the effects of the several fertilizers as if they were due to their characteristic ingredients. How we may make use of these figures in studying the effects of the several ingredients may be illustrated by the experiments with corn, as set forth in part one of Table X.

EFFECTS UPON CORN.

1. *Effect upon phosphoric acid, i. e., of superphosphate.*—In eight experiments, Nos. B, 3, 6, 7, 8, 14, B1, and B2, phosphoric acid was decidedly the regulating ingredient, the crop responding uniformly to it, and paying comparatively little attention to the others. In thirteen experiments, Nos. A, C, 5, 11, 12, 15, 16, 18, 20, 21, 22, 23, and 24, the phosphoric acid, though not holding relatively so important a place, was more or less useful. In six experiments, Nos. 2, 4, 10, 13, 17, and 19, the phosphoric acid produced little or no effect, the average increase of the several plots of each experiment being less than 4 bushels per acre.

2. *Effect of potash, i. e., of muriate of potash.*—In three experiments, Nos. D, 4, and 20, potash was decidedly the regulating ingredient, the crops responding uniformly to it, and paying comparatively little attention to the others. In fifteen experiments, Nos. A, B, 6, 9, 11, 12, 13, 14, 17, 18, 19, 21, 22, 23, and 24, potash, though not holding so important a place, was more or less useful. In ten experiments, Nos. 2, 3, 5, 7, 8, 10, 15, 16, A1, and A2, potash produced little or no effect, the average increase of the several plots of each experiment being less than 4 bushels per acre.

3. *Effect of nitrogen, i. e., of nitrate of soda.*—In no experiment was nitrogen the regulating ingredient. In sixteen experiments, Nos. A, B, 2, 4, 6, 9, 11, 12, 13, 14, 15, 17, 20, 22, 23, and 24, nitrogen, though not holding a very important place, was more or less useful. In ten experiments, Nos. 3, 5, 7, 8, 10, 16, 18, 19, and 21, nitrogen produced little or no effect, the average increase of the several plots of each experiment being less than 4 bushels per acre.

Going over the experiments with corn in 1878-'79-'80-'81, as set forth in Table X, we may group the results with reference to the facts of the individual ingredients as follows:

1. *Phosphoric acid.*—This may be taken as the regulating ingredient in the following experiments:

1878. Nos. B, 3, 6, 7, 8, 14, B1, and B2. 1879. Nos. C, 3, 7, 11, 14, 17, 18, and 26. 1880. Nos. 1, G, 4, 8, 9, C, 13, 14, 15, and 20. 1881. Nos. C, N, and Q.

As more or less efficient in—

1878. Nos. A, D, 5, 11, 12, 15, 16, 18, 20, 21, 22, 23, and 24. 1879. Nos. 4, 5, 6, 8, 9, F, 13, 15, 20, 21, 22, 23, and 25. 1880. Nos. K, 11, 12, I, 18, and 19. 1881. No. O.

As inefficient in—

1878. Nos. 2, 4, 10, 13, 17, and 19. 1879. Nos. 1, 12, 16, 19, and E, 1880. Nos. 3, 5, 7, and H. 1881. Nos. P, M, and L.

2. *Potash* may be regarded as the regulating ingredient in the following experiments:

1878. Nos. D, 4, and 20. 1879. Nos. 6, F, 15, 22, and E. 1880. Nos. 3, 5, 16, and H. 1881. Nos. O, P.

As more or less efficient in—

1878. Nos. A, B, 6, 9, 11, 12, 13, 14, 17, 18, 19, 21, 22, 23, and 24. 1879. Nos. 7, 9, 12, 14, 21, and 23. 1880. Nos. K, 9, 11, 15, 18, and 20. 1881. No. C.

As inefficient in—

1878. Nos. 2, 3, 5, 7, 8, 10, 15, 16, A1, and A2. 1879. Nos. 1, C, 3, 4, 5, 8, 11, 13, 16, 17, 18, 19, 20, 25, and 26. 1880. Nos. 1, G, 4, 7, 8, C, 12, I, 14, 19. 1881. Nos. Q, N, L, M.

3. *Nitrogen* may be taken as the regulating ingredient in the following experiments:

1878. None. 1879. No. 4. 1880. No. K. 1881. No. L.

As more or less efficient in—

1878. Nos. A, B, 2, 4, 6, 9, 11, 12, 13, 14, 15, 17, 20, 22, 23, and 24. 1879. Nos. 5, 6, 9, 11, 12, 13, 14, 21, 22, 25, and 26. 1880. Nos. 1, G, I, and 19. 1881. Nos. Q, P.

As inefficient in—

1878. Nos. 3, 5, 7, 8, 10, 16, 18, 19, and 21. 1879. Nos. 1, C, 3, 7, 8, F, 15, 16, 17, 18, 19, 20, 23, and E. 1880. Nos. 3, 4, 5, 7, 8, 9, C, 11, 12, 14, 15, 16, H, 18, 20. 1881. Nos. O, N, M, C.

The above data for the effects of the nitrogen, phosphoric acid, and potash upon corn may be tabulated together as follows:

Effects of the fertilizing materials upon corn.	Superphosphate.				Muriate of potash.				Nitrate of soda.			
	Regulating ingredient.	More or less efficient.	Inefficient.	Total.	Regulating ingredient.	More or less efficient.	Inefficient.	Total.	Regulating ingredient.	More or less efficient.	Inefficient.	Total.
In twenty-seven experiments of 1878.	8	13	6	27	4	13	10	27	......	16	11	27
In twenty-six experiments of 1879 ...	8	13	5	26	5	6	15	26	2	10	14	26
In twenty experiments of 1880	10	6	4	20	1	4	15	20	1	2	17	20
In seven experiments of 1881.........	3	2	2	7	2	1	4	7	1	2	4	7
In eighty experiments of 1878–'79–'80–'81	29	34	17	80	12	24	44	80	4	30	46	80

EFFECTS UPON POTATOES.

1. *Phosphoric acid.*—This may be taken as the regulating ingredient in the following experiments:

1878. Nos. 27, 32, 33. 1879. Nos. 27, C, 29, 30, 35, 37. 1880. Nos. 21, 22, 26. 1881. C, I.

As more or less efficient in—

1878. Nos. 26, 28, 29, 30, 31. 1879. Nos. 31, 34. 1880. No. C. 1881. No. M.

As efficient in—

1878. No. 25. 1879. Nos. 33, 36. 1880. Nos. 23, 25. 1881. None.

2. *Potash.*—This may be taken as the regulating ingredient in the following experiments:

1878. Nos. 26, 28, 29, 30, 31. 1879. Nos. 27, 31, 34. 1880. No. C. 1881. None.

As more or less efficient in—

1878. Nos. 27, 32, 33. 1879. Nos. 29, 30. 1880. Nos. 21, 26. 1881. C, I.

As inefficient in—

1878. No. 25. 1879. Nos. C, 33, 35, 36, 37. 1880. Nos. 22, 23, 25. 1881. No. M.

Nitrogen.—This may be taken as the regulating ingredient in the following experiments:

1878. No. 25. 1879. No. 36. 1880. No. 25. 1881. No. M.

As more or less efficient in—

1878. Nos. 27, 28, 29, 30, 31, 32, 33. 1879. Nos. 27, C, 29, 30, 31, 34, 35. 1880. Nos. 21, C. 1881. Nos. C, I.

As inefficient in—

1878. No. 26. 1879. Nos. 33, 37. 1880. Nos. 22, 23, 26. 1881. None.

The above data may be tabulated thus:

Effects of the fertilizing materials upon potatoes.	Superphosphate.				Muriate of potash.				Nitrate of soda.			
	Regulating ingredient.	More or less efficient.	Inefficient.	Total.	Regulating ingredient.	More or less efficient.	Inefficient.	Total.	Regulating ingredient.	More or less efficient.	Inefficient.	Total.
In nine experiments of 1878	3	5	1	9	5	3	1	9	1	7	1	9
In ten experiments of 1879	6	2	2	10	3	2	5	10	1	7	2	10
In six experiments of 1880	3	1	2	6	1	2	3	6	1	2	3	6
In three experiments of 1881	2	1	....	3	....	2	1	3	1	2	....	3
In twenty-eight experiments of 1878-'81	14	9	5	28	9	9	10	28	4	18	6	28

EFFECTS OF THE DIFFERENT INGREDIENTS IN SELECTED EXPERIMENTS.

The experiments from which the above figures have been taken were conducted under all the varying conditions to which plants are subjected in ordinary culture. Many of them were, of course, affected by weather, tillage, physical properties of the soil, and other conditions, in such ways as to materially disturb the normal action of the ingredients. And, further, the irregularities of the soil in many cases were such that generalizations could be based only upon averages of large numbers.

Accordingly my assistant, Mr. Voorhees, has gone over the tables, selected the experiments which were, according to the reports, comparatively free from the disturbing influences of drought, cold, &c., and whose results were reasonably uniform, and from these has prepared what we have called a selected table of differences. (Table XI of the Appendix.)

EFFECTS UPON CORN.

The results, taken from this table, as before, may be stated thus:

1. *Phosphoric acid* may be regarded as the regulating ingredient in the following experiments: Nos. B, 3, 8, 12, C, 7, 14, C, 80, 11, 15, 19, C, 81.

As more or less efficient in Experiments D, 9, 6, F, 22, H. O.

As inefficient in Experiments Nos. 4, E, 25, K, L.

2. *Potash* as the regulating ingredient in the following experiments: Nos. D, 4, 9, 6, F, 22, E, H, O.

As more or less efficient in Experiments Nos. B, 12, 7, 14, 11, 15, C, 81.

As inefficient in Experiments Nos. 3, 8, C, 25, K, C, 80, 19, L.

3. *Nitrogen* as the regulating ingredient in the following experiments: Nos. 25, K, L.

As more or less efficient in Experiments Nos. D, 4, 9, 12, 6, 14, 22, 19.

As inefficient in Experiments Nos. B, 3, 8. C, 7, F, E, C, 81, 11, 15, H, C, 81, O.

The above figures may be tabulated as follows:

Effects of the fertilizing materials upon corn.	Superphosphate.				Muriate of potash.				Nitrate of soda.			
	Regulating ingredient.	More or less efficient.	Inefficient.	Total.	Regulating ingredient.	More or less efficient.	Inefficient.	Total.	Regulating ingredient.	More or less efficient.	Inefficient.	Total.
In twenty-four experiments.	12	7	5	24	9	7	8	24	3	8	13	24

EFFECTS UPON POTATOES.

1. *Phosphoric acid* may be taken as the regulating ingredient in the following experiments: Nos. 27, 33, 31, 1879, 21, C, 1881, and I.

As more or less efficient in Experiments Nos. 26, 28, 29, 31, 34, C, 1880.

As inefficient in none.

2. *Potash* as the regulating ingredient in the following experiments: Nos. 26, 28, 29, 31, 1879, 34, C, 1880.

As more or less efficient in Experiments Nos. 27, 33, 21, C, 1881, I.

As inefficient in none.

3. *Nitrogen* as the regulating ingredient in none.

As more or less efficient in Experiments Nos. 27, 28, 29, 31, 33, 31, 1879, 34, 21, C, 1880, C, 1881, I.

As inefficient in No. 26.

Or, tabulating as before, we have:

Effects of the fertilizing materials upon potatoes.	Superphosphate.				Muriate of potash.				Nitrate of soda.			
	Regulating ingredient.	More or less efficient.	Inefficient.	Total.	Regulating ingredient.	More or less efficient.	Inefficient.	Total.	Regulating ingredient.	More or less efficient.	Inefficient.	Total.
In twelve experiments...	6	6	0	12	7	5	0	12	0	11	1	12

It is a very striking fact that the potatoes should have responded well to the three ingredients in nearly every case where drought or other untoward conditions did not interpose.

This particular part of the discussion will be resumed further on. Meanwhile we may devote a few words to the relations of corn to the nitrogen supply.

RECAPITULATION OF THE EFFECTS OF NITROGENOUS FERTILIZERS UPON CORN.

Estimating a bushel of corn, with its cobs and stalks, to contain $1\frac{1}{3}$ of nitrogen, and to be worth 80 cents, the effects of the nitrogenous fertilizers in the special and in the general experiments may be summarized as follows, remembering that the superphosphate and potash salt, "mixed minerals," supplied the amounts of phosphoric acid and potash in a crop of not far from 55 to 60 bushels, which would also contain about the 72 pounds of nitrogen.

Average results of experiments with corn in 1878, 1879, 1880, *and* 1881.

[Bushels of corn and pounds of nitrogen in crop per acre.]

	Corn.	Nitrogen.
Eighteen special experiments.	*Bushels.*	*Pounds.*
"Mixed minerals" alone	43.0	60.4
Same +24 pounds nitrogen	48.4	72.7
Same +48 pounds nitrogen	48.8	73.8
Same +72 pounds nitrogen	49.6	75.6
Seventy-five general experiments.		
"Mixed minerals" alone	43.4	57.8
Same +24 pounds nitrogen	47.8	63.7

In the general experiments of the mixture of 300 pounds of superphosphate and 200 pounds muriate of potash brought, on the average of fifty-three experiments, about 43½ bushels of shelled corn per acre. The special experiments, however, seem to me a fairer test of what the fertilizers may do, because, while made in all sorts of weather and on worn-out soils, they were nearly all on soils and in latitudes fit for corn, as many of the general experiments were not. In these the mixture of 300 pounds of superphosphate and 150 pounds of potash salt, which can be bought for $8.25, brought, on the average, 43 bushels of shelled corn per acre. Omitting Mr. Newton's experiment (Appendix, Tables I and III), the results of which are very exceptional, the average is 44½ bushels.

The experiments of the four seasons bear almost unanimous testimony to two things: The corn was helped but little by nitrogen in the fertilizers; and it gathered a good deal from natural sources. The increase of crop and of nitrogen in the crop will appear more clearly if we look at it another way:

Date.	In number of trials.	With nitrogen. Amount per acre.	With nitrogen. Contained in crop of—	The average increase of corn was—	The increase of nitrogen in the crop was—
		Pounds.	*Bushels.*	*Bushels.*	*Pounds.*
1877–'78	29	24	18	5.9	7.9
	15	48	36	7.6	9.1
	6	72	54	9.3	12.4
1879	26	24	18	5.9	7.9
	14	48	36	1.9	2.5
	6	72	54	0.3	0.4
1880	20	24	18	0.6	0.8
	24	48	36	9.0	12.0
	10	72	54	14.3	19.0
1881	20	24	18	1.9	2.5
	23	48	36	3.1	4.1
	20	72	54	5.0	6.7
1877–'81	95	24	18	3.6	4.8
	76	48	36	5.3	7.1
	42	72	54	6.6	8.8

Or, considering the nitrogen as paying for itself when the value of the increase of crop that came with its use equaled or exceeded the cost of the nitrogen, and expressing the results in dollars and cents:

Date.	In trials, total number.	With nitrogen am'nts.	Costing.	The nitrogen paid for itself in trials—	The nitrogen failed to pay for itself in trials—	The average loss in the several trials was—
		Pounds.				
1877-78	29	24	$5 50	8	21	$0 90
	15	48	11 00	1	14	4 45
	6	72	16 50	None.	6	8 51
1879	26	24	5 50	5	21	90
	14	48	11 00	1	13	8 48
	6	72	16 50	None.	6	16 26
1880	20	24	5 50	4	16	2 34
	24	48	11 00	9	15	6 04
	10	72	16 50	2	8	10 10
1881	20	24	5 50	4	16	3 98
	23	48	11 00	2	21	8 52
	20	72	16 50	2	18	12 50
1877-81	95	24	5 50	21	74	2 62
	76	48	11 00	13	63	6 76
	24	72	16 50	4	38	11 22

The only cases in which the largest rations were profitable were in the experiments of Mr. Newton.

The above calculations of pecuniary loss and gain of course apply only to those regions where corn is dear. But even at these rates the nitrogen increased the crop enough to pay its costs in only 38 trials out of 213. The pecuniary loss rose and fell with the amount of nitrogen used. With mineral fertilizers alone the crop gathered, by the above estimates, some 60 pounds of nitrogen per acre.

The important fact, however, is this: The corn plant has in these trials shown itself capable of getting on and bringing fair yields with small amounts of the less costly mineral fertilizers, even in the worn-out soils of the Eastern States. With this help it has gathered its nitrogen from natural sources, and holds it readily to be fed out on the farm and returned in the form of manure for other crops. In other words, the experiments thus far imply that corn has, somehow or other, the power to gather a great deal of nitrogen from soil or air, or both; that in this respect it comes nearer to the legumes than the cereals; that, in short, corn may be classed with the "renovating" crops. If this is really so, and this can be settled only by continued experimenting, then our great cereal, instead of being simply a consumer of the fertility of our soils, may be used as an agent for their restoration.

THE DOMINANT FERTILIZING INGREDIENTS.

The experiments and the theory of M. Ville.—It will be interesting to note in how far the theory of "dominant ingredients" is borne out by

the experiments. According to Ville the "dominant" for corn is phosphoric acid.

The effects of nitrogen, phosphoric acid, and potash are very clearly shown above, in the discussion of the "table of differences." As there shown (see Tables X and XI of the Appendix and the recapitulation above), in some of the experiments the phosphoric acid was a decidedly regulating ingredient, the corn respond uniformly to it, and pay comparatively little attention to the others. In others the superphosphate, though not holding so important a place, was more or less useful. In still others the superphosphate produced little or no effect, the average increase of the several plots in each experiment being less than 4 bushels per acre. In like manner the potash was occasionally, though less often, the regulating ingredient. Often it had a considerable effect, but as often produced no marked results. The nitrogen may be regarded as the regulating ingredient in only a very few trials, and of these nearly all were in a single field, in which the experiments of Mr. Newton were made.

In brief, phosphoric acid took the leading place often, potash occasionally, and nitrogen very rarely. In bad seasons, and on some soils in good seasons, neither material had any effect. The most effective ingredient depended upon soil and season.

IS CORN IN ITS RELATIONS TO NITROGEN MORE CLOSELY ALLIED TO THE CEREALS OR THE LEGUMES?

In relation to this question I can do no better than repeat what was said in a previous report:

Our experiments imply that corn shares, to a considerable extent, the power of the legumes for gathering nitrogen from natural sources. One thing, however, detracts from their decisiveness. Most of the trials were on old grass land which contained large quantities of roots on which the corn doubtless fed. How well it could provide itself with nitrogen from nitrogen compounds in the soil and from air without the roots to feed upon is not settled.

The experiments are numerous and decisive enough to warrant the inference that, as corn is commonly grown, nitrogenous fertilizers in any considerable quantity would be rarely profitable. They imply that corn has somehow or other the power to gather a great deal of nitrogen from soil or air, or both; they imply that in this respect it comes closer to the legumes than the cereals—that, in short, corn may be classed with the renovating crops.

THE FEEDING CAPACITIES OF POTATOES AND OTHER PLANTS.

Our experiments throw some light upon this question, as may be seen especially in Tables X and XII of the Appendix. Thus, in the experiments of Mr. Bartholomew, detailed in No. C of Tables I and II, corn and potatoes were grown side by side under precisely similar treatment.

The corn paid scarcely any attention to the potash and very little to the nitrogen, but responded largely to the phosphoric acid. The potatoes, on the contrary, were helped in a very marked degree by superphosphate and potash salt, and by nitrogen in all its forms—nitrate of

soda, sulphate of ammonia, dried blood, the mixture of all these, and Peruvian guano. Experiments on adjacent fields have brought exactly concordant results. In Mr. Bartholomew's four years' experimenting both crops have uniformly responded to phosphoric acid; but, while corn has paid little heed to nitrogen in commercial fertilizers in any form, and almost none to potash, potatoes have as regularly responded to both.

Similar results may be observed in the experiments of Mr. Benson in Tables VI and VII of Appendix, and Professor Jordan (Tables I and VII), in which corn and potatoes were grown side by side. In the experiments of Mr. Fairchild, also, which are detailed in the tables, corn and potatoes have both responded to all three ingredients. But while the corn has paid but little heed to potash, scarcely any to nitrogen, the potatoes have been largely benefited by both.

If potatoes get so much help from nitrogen and potash in Mr. Bartholomew's land, where corn can provide itself with these materials without aid from fertilizers, it would seem fair to expect them to respond to the same materials in almost any place where weather and other circumstances favor their growth. Exactly this is the case in the experiments in general, as may be seen by reference especially to Tables X and XI, and the recapitulation of the figures in the discussion above.

In brief, the results obtained each successive season confirm the statement made in a former report, that—

Taking all in all, the potatoes responded to the superphosphate, potash salt, and nitrogenous fertilizers in almost every case where the weather permitted fair growth. None of the other crops except, perhaps, turnips have shown such uniformly beneficial results from all the materials.

The experiments indicate very decidedly that the potato plant differs from many others in respect to the effect of these fertilizing materials upon its growth, and imply that it has less capacity than corn for gathering an adequate supply of food from natural sources. It seems to demand a full and immediately available supply of nourishment for its successful growth.

Concerning the other crops, the data at hand are too meager to warrant any general conclusions. * * * In general, however, the experiments accord with the common notion that makes superphosphate almost a specific for turnips. But they imply that even when the superphosphate is supplied in abundance, the turnip is not usually able to gather enough of the other materials for a full yield unless they are close at hand in readily available forms.

THE TEACHING OF THE EXPERIMENTS REGARDING FORMULAS FOR FERTILIZERS.

Ville's formula for an acre of corn, as explained above, is as follows:

Materials.	Ingredients.	Cost in formula.	In cheapest form.
Nitrate of potash, 180 pounds; Acid phosphate of lime, 540 pounds	Nitrogen, 24 pounds	$9 20	$4 80
	Phos. acid, 81 pounds	9 45	9 45
	Potash, 79 pounds	7 00	3 56
Sulphate of lime, 360 pounds		1 44	1 44
		27 09	19 25

The prices of the valuable ingredients are stated both as M. Ville recommends and as they may be bought in the equally good and cheaper materials, like nitrate of soda, guano, bone, and potash salts, which, with many important facts in agricultural chemistry, his system curiously ignores.

It is questionable whether so much of superphosphate or plaster as this formula requires would be often profitable. In the experiments potash was frequently, and nitrogen in small quantities occasionally, profitable, but the idea of using such a costly material as nitrate of potash to furnish them is economically absurd.

As long as soils and seasons continue to differ, then formulas to fit all cases are simply out of the question. At the same time there are many cases in which a man does not know what his soil requires, and can better afford to use a complete fertilizer, and pay the penalty of his ignorance in the purchase of superfluous materials, than to run the risk of losing his crop. Formulas are irrational, but they mark the first step in the progress toward rational fertilization.

THE EFFECTS OF NITROGEN IN DIFFERENT FORMS OF COMBINATION.

In comparing the effects of nitrogen in the forms of nitric acid, ammonia, and organic nitrogen, I had expected to find some marked differences; enough, perhaps, at least, to show a balance in favor of one or the other; but a careful study of Table XII of the appendix, where a very considerable number of comparative trials are averaged together, fails to show any marked excess of yield by either, in the experiments with either corn or potatoes. Those with the other crops have been too few to warrant any generalization.

FURTHER SUMMARY OF EFFECTS OF INGREDIENTS OF FERTILIZERS.

I give further results of the experiments as shown by the tables in the appendix, especially the "tables of difference," Tables X and XI of the appendix.

1. In a report of the experiments of 1878 it was stated that: The effects of the different materials on the poorer soils were generally very uniform. On the better soils they were more varied. This fact supports the view that the experiments are generally reliable as tests of the wants of worn-out soils, those which have only their natural strength to rely upon; but are not to be depended upon for rich soils, those that have an accumulated store of plant-food to draw from.

2. It is commonly stated that superphosphates, potash salts, and other like materials are more effective when used together than separately. That complete fertilizers are more reliable and effective than partial fertilizers is very certain. But if it is meant that the increase from the use of a given material, as potash salt, is greater when it is applied with other fertilizers than when it is used alone, the assertion

is not supported so decidedly by these experiments. Still, on the whole, the balance is in favor of the use of mixtures. This has been especially true in the experiments with potatoes. Here nitrate of soda, superphosphate, and muriate of potash have each been much more efficient in the complete fertilizer than alone or in the partial fertilizers.

3. NITRATE OF SODA was most effective where used in connection with other materials on potatoes. Alone on potatoes, and either alone or with other materials on corn, it was generally unprofitable, though in a few cases the results are very striking. As regards the other crops, the data are insufficient for generalization.

4. SUPERPHOSPHATE.—Superphosphate has proved profitable for corn usually, and for potatoes in every case where bad weather and other untoward circumstances did not interfere. It has been most useful on the poorer and medium soils. With corn on the rich soils it has had less and sometimes almost no effect.

5. PLASTER.—The effect of the plaster has been extremely variable; sometimes quite unpronounced, and sometimes very marked.

6. MURIATE OF POTASH proved profitable with corn very frequently; with potatoes in nearly every case where not interfered with by bad weather and other disturbing causes. Contrary to the common doctrine, potash salts did not prove more efficient with other fertilizers than when used alone, though, of course, the best results were obtained when it was used with other fertilizing materials. It is noticeable that in cases of drought, or where the fertilizers were applied in the hill or drill, both muriate of potash and nitrate of soda were often injurious. With the mixture, too, this was especially the case.

THE EFFECTS OF FERTILIZERS ON THE DIFFERENT KINDS OF SOIL.

I think that the more carefully the tabular statement of the results are studied the more correct will the following statement, from one of the reports of experiments above referred to, appear:

> Indeed, without more and more definite data than are given by these or any other field experiments I have ever known of, I see no prospect of getting at any reliable generalizations as to the kinds of soils on which such fertilizers are or are not beneficial. The fact is that the circumstances of composition, texture, absorptive power, and relations to moisture and heat of the soils, of climate and season, of previous tillage, manuring, and crops are so complex and variable that no such empirical experiments as it is possible to carry on in field culture can bring full and definite information as to the ways in which soils and fertilizers supply food to plants or otherwise affect their growth. These problems must be also studied by the more accurate methods and with the control of conditions which are possible only in culture on a small scale, in the greenhouse or garden, and with the appliances and help of the laboratory.

EFFECTS OF THE DIFFERENT FERTILIZERS UPON THE QUALITY OF THE CORN.

In an account of the experiments in the report of Connecticut Board of Agriculture for 1880, some statements were given respecting the

effects of the different fertilizers upon the quality of the corn, and the ratio of stalks to grain. It seemed worth while to collate the figures, if for no other purpose than to test the correctness of the theories often broached respecting the effect of nitrogen, phosphoric acid, potash, &c., upon the crop. As will be seen from the following extract from the report referred to, no very definite theory is borne out by the experiments. It has not seemed to me, therefore, worth while to carry the computations into the experiments of 1881.

The effects of the different fertilizers on the proportion of good to poor corn, and of corn to stalks, are worth noting. A number of experimenters reported the amounts of "good" and "poor" corn. The percentages of "good" corn, *i. e.*, the number of pounds in 100 pounds total corn as reported by the experimenters, are:

Number of pounds of good corn in 100 *pounds of total corn, with the different fertilizers.*

Number of experiment.	O. Nothing.	A. Nitrogen.	B. Phosphoric acid.	C. Potash.	D. Nitrogen and phosphoric acid.	E. Nitrogen and potash.	F. Phosphoric acid and potash.	G. Nitrogen, phosphoric acid, and potash.	H. Plaster.	Farm manures.
2	49	49^{6}	68^{5}	53^{5}	69^{6}	60^{3}	68^{7}	^{5}	^{5}	......
3	69	78	86	83	60	83	63	83	85	......
5	61	71	55	77	84	80	86	90	56	80
8	62	67	84	75	85	53	76	63	58	......
9	69	74	74	63	78	......	79	79	54	......
10	80	72	93	70	87	62	91	92	89	......
12	......	80	83	80	87	83	93	92	90	......
13	88	87	91	88	92	82	94	94	......	......
14	87	89	87	77	80	80	86	86	90	90
17	95	93	97	98	99	99	99	98	99	......
19	97	97	97	97	98	97	98	99	97	......
20	95	95	94	92	97	95	97	97	97	......
Average of twelve experiments in 1880	71	79	84	79	85	79	86	88	82	90
Average of fourteen experiments in 1879	56	58	72	62	73	64	61	69	63	58
Average of eight experiments in 1878	65	67	72	80	72	86	86	85	73	81
Average of thirty-four experiments in 1878–'80	63	68	76	72	77	74	76	79	72	68

The figures accord with the common experience that the largest yield gives also the largest proportion of good corn. Otherwise, no relation between the fertilizers and the proportions of good and poor corn is discoverable.

RATIO OF STALKS TO SHELLED CORN.

The weighings of corn and stalks were made at different stages of dryness. In some cases the stalks were cut above the ears, in others close to the ground. The results are consequently discrepant. The averages are interesting as showing the relative effects of the fertilizing materials.

Number of pounds of stalks to 100 pounds of shelled corn.

Number of experiment.	O. Nothing.	A. Nitrogen.	B. Phosphoric acid.	C. Potash.	D. Nitrogen and phosphoric acid.	E. Nitrogen and potash.	F. Phosphoric acid and potash.	G. Nitrogen, phosphoric acid, and potash.	H. Plaster.	Farm manure.
2	464	423	115	127	240	151	288	......	......	....
3	390	223	145	219	406	182	571	291	305	....
4	168	199	92	175	158	159	159	170	158	126
5	118	98	126	123	108	121	154	131	150	85
8	93	86	65	104	91	108	98	130	107	....
9	102	198	96	101	97	......	92	102	99	....
13	129	111	111	147	108	168	124	122	......	....
14	81	122	94	174	94	163	175	174	89	130
16	196	99	106	103	95	83	91	94	101	....
18	118	108	112	116	108	111	109	129	106	....
Average of ten experiments in 1880	186	159	106	139	151	138	186	149	142	114
Average of twelve experiments in 1879	149	156	120	168	105	162	141	124	219	115
Average of ten experiments in 1878	173	143	149	145	129	176	128	131	139	133
Average of thirty-two experiments in 1878–'80	168	153	125	151	127	158	150	133	172	122

The proportion of stalks to shelled corn is smaller in the larger crops, and conversely the poorer crops have more stalks for the same amount of corn than the better crops. Contrary to what is commonly supposed, the nitrogenous fertilizing materials do not seem to have increased the amount of stalks as compared with corn.

MODE OF APPLYING THE FERTILIZERS, WHETHER BROADCAST OR IN THE HILL OR DRILL.

The following is from an account of the experiments in one of the Connecticut reports referred to:

The testimony of the experiments is on the whole against applying in the hill or drill. The best results in the majority of cases came where the fertilizers were sown broadcast. Several of the very best were where the materials were scattered over a strip a couple of feet or so wide along the rows. Many of the worst results were where the fertilizers were put in the hill or drill. The nitrate of soda and potash salts thus applied often injured the crops, especially in dry weather. The following from the directions for the experiments is not out of place here:

"The fertilizers may be applied broadcast, or, if more convenient, they may be put in the hill or drill, *provided they are well diffused through the soil.* To accomplish this, they had better be diluted with several times their bulk of earth before using. The important points are, that they be—

"1st. Applied evenly over the plots where they belong and not allowed to get outside.

"2d. Well distributed through the soil.

"Experiments with concentrated fertilizers are often spoiled, just as crops are injured or lost through wrong application. Farmers are apt to think that the manure must be put close to the seed or the plant will not get the benefit of it. This is wrong. It is not the just germinated plantlet that needs the manure, but the plant, from the time it is well started until its growth is done. We want, not only to give the crop a good start, but to help it out on the home stretch as well. The roots and their branching rootlets run out in all directions in search of food, and the fertilizers ought

to be where as many of the rootlets as possible can get at them. If we distribute the fertilizers as well as we can, the water in the soil, aided by the chemical and physical forces that nature keeps in operation, will do the rest. In illustration of this remember how well barn-manure acts when applied as a top-dressing long before the seed is put in.

"But if we concentrate the fertilizers in one place fewer roots will get them, and these may be injured by coming in contact with them or with their concentrated solutions in the soil. The roots will find their way to the manure and develop more where it lies, it is true, still we should not oblige them to huddle together in one place, but should rather encourage them to spread around, where, with the increased capacity the fertilizer gives them, they can get the more from the soil. Roots join with other natural agents in rendering inert stores of plant food available.

"Above all, do not let the fertilizers come too close to the seed. A coarse, dilute material like yard manure may do the plants no harm, but such concentrated fertilizers as potash salts, dried blood, nitrate of soda, or high grade superphosphates may kill them."

CHEMICAL FERTILIZERS VS. FARM MANURES.

Of course no fair comparisons can be made between the artificial fertilizers whose composition was definite and constant, and the farm manures whose amount and quality were so variable and uncertain. It seems fair to presume, however, that the men who make these experiments would apply liberal doses of good manure on the small plots. The average yield and increase from the farm manures, complete fertilizer G, and mixture of superphosphate and potash salt F, in the experiments in which the farm manures were used, were as shown in the table giving averages of results of experiments of 1878 and 1881:

		Bushels per acre.		
		Farm manures.	Complete chemical fertilizer.	Mixture of superphosphate and potash salt.
Corn	Produce	45.3	47.7	41.8
	Increase	20.5	22.9	17.0
Potatoes	Produce	130.1	154.6	123.9
	Increase	58.0	82.5	56.8
Turnips	Produce	374.0	501.0	401.0
	Increase	129.0	256.0	156.0

The following statements, from the Connecticut report referred to, are in place here:

The yield and increase of corn, potatoes, and turnips were much larger with the complete chemical fertilizer than from the farm manures. The mixture of superphosphate and potash salt excelled the farm manures with potatoes and turnips, and fell slightly behind them with corn.

Concerning quality of crop, as previously stated the few experimenters who reported definitely pronounced in favor of the chemicals, especially for potatoes, which they say are smoother and less disposed to rot with the chemicals than with the farm manures.

In very many of the cases where the weather was reported especially unfavorable on account of excessive cold, wet, or drought, the chemicals have brought better

yields than the farm manures. Farm manures have the advantage over chemical fertilizers in that their organic matter tends to improve the mechanical condition of soils, counteract drought, and aid in rendering soil-food available, and perhaps to facilitate the assimilation of atmospheric nitrogen also. Concentrated fertilizers have the advantage of supplying the food in readily available forms, while they also aid in improving the texture of the soil and setting plant-food free in various ways not fully understood.

Mr. Lawes, of Rothamsted, says that to get large crops he would use artificial fertilizers rather than farm manures. Ville claims like superiority for the chemicals, and cites averages of some hundreds of experiments in proof. But I have always felt a little skeptical, and must confess that, especially in view of the small quantity of chemicals used in these experiments, the heavy balance in their favor, even in bad weather, has surprised me.

As to how the after effects of the two classes of materials will compare the future must decide. I should expect the farm manures to be more lasting. Speaking roughly, the mixture of superphosphate and potash salt contains about as much of the mineral elements of plant-food as eight or ten tons of good, well-cured stable manure. The complete fertilizer contains also about one-third or one-fourth as much nitrogen as the same quantity of manure. The bulk of the phosphoric acid and potash of both will stay in the soil until removed by plants. The nitrogen is exposed to more or less rapid loss by entering into insoluble compounds in the soil, by leaching away beyond the reach of plants, and by escaping as free nitrogen into the air. It would seem fair to expect that the effect of a dressing of stable manure, with its slower action and larger proportion of nitrogen, would last longer than the chemicals.

PRACTICAL APPLICATIONS.

The general results of the experiments taken together may be summed up nearly as follows:

1. It must be remembered that the trials were not only subject to all the vicissitudes of the weather and season, heat and cold, heat and drought, but were made on soils of all sorts, mostly very poor. The directions were to select worn-out soils, and often they were ill-adapted to the crops grown upon them; hence the average results with a given crop do not fairly represent what might be expected under favorable conditions and on soils adapted to its growth.

2. The largest yield came with the "complete" chemical fertilizer (*G*) (see "description of general experiments," and Tables IV and IX of Appendix), which supplies 150 pounds of nitrate of soda, 300 pounds of superphosphate, and 150 to 200 pounds of muriate of potash, at a cost of a little over $15 per acre.

No. G has brought by far the best results. It was generally the most profitable of all with potatoes, and often so with corn and other crops. This mixture has not only brought larger yields than the farm manures, but has also proved more certain, in favorable seasons and in cold, wet, and drought. I would not propose these proportions for general use, however. Less potash and more nitrogen would often be better, especially for grain, potatoes, and garden vegetables. The object here was to test soils, and not to get the largest possible yields.

3. The next largest average yield is with the farm manures. Then

follows the mixture of superphosphate and muriate of potash (*F*). This latter averaged most profitable of all for corn.

4. Next came the mixture of nitrate of soda and superphosphate (*E*). That this, which contained superphosphate and nitrate of soda, should bring a lower average yield than the mixture of superphosphate and potash salt with every crop on which the number of trials is large enough to warrant any general conclusions, is certainly a significant fact. Our ordinary guanos, ammoniated superphosphates, and fish manures contain (like *E*) nitrogen and phosphoric acid with a little or no potash. Nitrogen is the costliest, and potash one of the cheaper, of the valuable ingredients of ordinary fertilizers. Continued experience emphasizes the statement that manufacturers and users of ammoniated superphosphate would do well to consider the propriety of either adding potash salts or substituting them for nitrogenous materials in their fertilizers. Indeed, I see many are doing so.

5. The mixture of nitrate of soda and potash salt was the least efficient of all.

6. As to the efficiency of the materials separately, the nitrate of soda was rarely, the sulphate of lime frequently, the muriate of potash very often, and the superphosphate generally, useful. Doubtless considerable of the effect of the superphosphate was due, in many cases, to the sulphuric acid and lime.

7. The results with ashes are variable, though, generally speaking, they have been efficacious.

8. One of the chief defects of these experiments is that so few parallel trials with lime have been made. There are many cases in which a dressing of lime is the cheapest and best means of improving the land.

ARTIFICIAL FERTILIZERS VS. FARM MANURES.

9. Not only did the complete chemical fertilizer bring a larger average increase than farm manures as actually used, and the mixture of superphosphate and potash salt nearly as large, but the quality of the crop was generally better with the chemicals. Potatoes especially were finer in quality and less disposed to rot with the artificial fertilizers than with the farm manures.

AS TO THE EFFECT OF THE FERTILIZERS UPON DIFFERENT CROPS.

10. Potatoes and turnips responded most profitably to the complete fertilizer in nearly every case. Corn, on the other hand, was largely helped by the superphosphate and potash salt, but received but little benefit from the application of nitrogen in any form.

AS TO THE FEEDING CAPACITIES OF THE CROP.

11. The experiments imply that corn, somehow or other, was able to gather a fair supply of nitrogen from natural sources provided it had

enough of the mineral ingredients at its disposal. They do not tell how much of the nitrogen came from the roots of preceding crops, how much from other nitrogen compounds in the soil, and how much from the air. They imply that the potato possesses in far less degree than corn the power of gathering sufficient supply of either nitrogen or the other ingredients of its food from soil and air. They imply that turnips are generally unable to provide themselves with phosphoric acid from the soil, and are greatly helped by it in fertilizers; that without an abundance of phosphoric acid they get but little good from other materials; that with it they can gather a partial supply of the other materials of their food, but that for a full yield considerable quantities of all the soil ingredients of plant-food are needed close at hand and in available forms. Except on corn and potatoes, however, the experiments are still too few for reliable inferences.

OTHER CONDITIONS AFFECTING THE ACTION OF FERTILIZERS.

12. The most profitable material in a given case is that which is best fitted to its needs. The chief factors of the problem are:

First, soil.

Second, climate and season.

Third, feeding capacity of crop.

Fourth, form of combination of the ingredients of the fertilizer.

Fifth, the indirect action of the fertilizer, *i. e.*, its effect upon the texture of the soil; upon its power to absorb and retain plant food; in setting other plant food free.

Sixth, the composition of the plant.

Soils vary in respect to the *plant food* they supply in available forms. Phosphoric acid is most often deficient; next come potash and nitrogen; then lime and sulphuric acid, and rarely magnesia.

But the infertility of soils is due to other causes perhaps nearly as often as to lack of plant food. Soils often do not have the proper texture—they are too compact or too loose; or they are too shallow; or they lack absorptive power—they cannot retain the plant food until plants use it, but suffer it to be leached away by drainage water; or the moisture supply is bad—they are too wet or too dry. These defects are as fatal as lack of plant food. Many soils need amendments first and then manure.

Climate and season counts for much, often for everything, in the action of manures. This fact is certain. Of the reasons we know, as yet, but little.

As to effects of the *forms of combination*, nitrogen seems to do better in materials that contain it in several forms, as Peruvian guano, or a mixture of nitrate of soda, sulphate of ammonia, and dried blood, than in either of the latter substances singly. The effects of phosphoric acid and potash in different forms were tested in too few cases to warrant any conclusions.

As to the *indirect action* of fertilizers in improving the texture of the soil and setting its plant food free, the experiments have nothing to say, but we know that it often makes a large part of the usefulness of the fertilizer.

THE BEST FERTILIZERS FOR DIFFERENT CROPS.

13. It is perfectly evident, therefore, that there is no *best* fertilizer for any crop, and that formulas to fit all cases are out of the question. There are many cases, however, in which complete fertilizers are in place. There are also many in which the farmer does not know what his soil and crops need, and can better afford to pay for some unnecessary materials in a complete fertilizer than to risk the loss of his crop. But for this demand dealers offer a supply. Instead of proposing formulas, I urge farmers to study their soils and circumstances and learn what is best for them to use.

14. The common impression among farmers that the best use of artificial fertilizers is to supplement farm manures is doubtless, in ordinary circumstances, correct.

15. Leaving variations in soil and season out of account, and considering the feeding capacity of the crops, as shown by these and other experiments and by general experience, it is safe to say that—

(1) For *corn*, an excellent fertilizer to bring large crops would be a mixture of some material containing nitrogen and phosphoric acid, as Peruvian guano, or fish guano, and muriate of potash. To this it might be profitable to add some fine-ground bone or superphosphate. In the majority of cases, though not always, a more profitable mixture would probably be one of muriate of potash, with either superphosphate or fine-ground bone, or both. At the same time there are cases in which nitrogen helps the crop enough to make it profitable, and in which nitrate of soda, sulphate of ammonia, dried blood, guano, or fish, would be in place.

(2) For *potatoes*, which respond more generally than corn to both nitrogen and potash, such of the above mixtures as contain considerable nitrogen would generally be in order.

AS TO COMMERCIAL FERTILIZERS IN GENERAL.

16. For general farming, at a distance from the large markets, the chief use of commercial fertilizers should be to supplement the manure of the farm. The right way is to make the most and best manure that is practicable upon the farm, and piece out with such commercial fertilizers as experiments and experience prove profitable. At the same time there are many cases, especially near cities, where everything depends upon getting the largest and best yield, and where more exclusive use of chemical fertilizers is advisable.

IN CONCLUSION.

Taken all together, the experiments emphasize more and more strongly, year after year, the conclusions expressed in previous reports that:

17. Soils vary widely in their capacities for supplying crops with food, and consequently in their demand for fertilizers.

18. Some soils will give good returns for manuring; others, without previous amendment, by draining, irrigation, tillage, or use of lime, marl, &c., will not.

19. Farmers cannot afford to use commercial fertilizers at random, and it is time they understood the reason why.

20. The right materials in the right places bring large profits. Artificial fertilizers, rightly used, must prove among the most potent means for the restoration of our agriculture.

21. The only way to find what a soil wants is to study it by careful observation and experiments.

PLANS FOR CO-OPERATIVE EXPERIMENTS.

The report of proceedings of a convention held at the Department of Agriculture contains a paper on the subject of Co-operative Experiments as a Means of Studying the Effects of Fertilizers and the Feeding Capacities of Plants.

With a special issue of this address, published by the department, were given some suggestions for experiments which it seems proper to reproduce here:

In organizing a system of co-operative experimenting, the one great need is an official and influential center, whence suggestions and plans for work may emanate, and where reports of results may be collated, arranged, and published, and with whose wise aid all can work together. By the espousal of the enterprise by the Agricultural Department at Washington, under its present very efficient management, this want is most happily met. And nothing could be more auspicious for such a union between the department and the best experimenters of the country than the discussions and action of the late convention.

PLANS FOR EXPERIMENTS.

In accordance with a request from the Commissioner of Agriculture, I have undertaken, with the aid of several well-known workers in this line, to prepare some plans for experiments; doing so, however, with the feeling that what is wanted is not detailed and inelastic schedules, but rather, outlines which each experimenter can fill in as seems to him most advisable. Every man knows his own circumstances, and every intelligent worker has valuable ideas of his own, which others have not. It seems to me that the most effective system will be one which will enable each to develop his own ideas, while we all work together and contribute our results to the common fund.

KIND OF INVESTIGATIONS THAT ARE NEEDED.

To get the most complete results we need:

I. Field experiments, to include—

a. The culture of plants on plots of land treated with different manures, and careful weighings and measurements of produce.

b. Where practicable, chemical and physical studies of the soil.

c. In many cases, chemical analyses of the plants.

II. Pot experiments, in which the conditions can be definitely known and controlled, and the needed studies of soil and plants be carried out with equal or greater convenience and accuracy.

Indeed, it is safe to say that there ought to be in the various sections of the country chemical and physical surveys of the land in the behalf of agriculture, as there have been topographical and geological surveys in the behalf of other industries and interests. And in fact this is precisely the direction in which we are tending in this experimental work.

The subjects proposed at the Washington convention for co-operative experiments were:

1. The supply of nitrogen to plants.

2. The action of phosphoric acid in different forms of combination and in different fertilizing materials upon the growth of plants.

Practically, so far as field experiments are concerned, these two subjects reduce themselves to the study of the action of nitrogenous and phosphatic fertilizers

The first thing, then, will be to see what materials are to be employed.

Since similar questions regarding potash will naturally arise, it may be well to include brief suggestions regarding potassic fertilizers. Of course sulphuric acid, lime, and magnesia could be treated in like manner if it should hereafter become desirable.

QUANTITIES OF MATERIALS TO BE USED.

To decide what quantities of materials will be best for the purpose is not easy, because of the lack of the very data for which the experiments are, in part, to be made. Neither the proportions which occur in any crops, nor those in farm manures, could well serve as a standard. Probably the best plan will be to endeavor to select, as extremes, the smallest and the largest quantities that general experience has brought into ordinary use, and arrange intermediate quantities at proper intervals between.

Nitrogen.—A dressing of 450 pounds of nitrate of soda per acre is probably as large as would be apt to be used in this country, in ordinary practice, on ordinary crops. At the same time it is no more than has been found profitable in previous nitrogen experiments, and is perhaps as small as would be advisable for the maximum. At 16 per cent. it would contain 72 pounds of nitrogen.

Three hundred pounds of an ammoniated superphosphate with 3 per cent., or 9 pounds, of nitrogen, is not an unusual dressing per acre. As little as 200 pounds, with only 6 pounds of nitrogen per acre, is a common quantity for cotton, and, indeed, for other crops, when applied in the hill or drill or as a supplement to other manures. Six pounds of nitrogen is a very small quantity for an acre of land. Twelve pounds, which would be contained in 75 pounds of nitrate of soda, would seem to be little enough. Still it will be well to provide for as small an amount as is ordinarily used.

In arranging the rations it would seem best to make the difference between the smaller rations less than that between the larger ones. In the previous nitrogen experiments, three rations, "one-third," "two-thirds," and "three-thirds," with 24, 48, and 72 pounds of nitrogen per acre, respectively, have been employed. Prefacing these by a "one-twelfth" ration of 6 pounds, and a "one-sixth" ration of 12 pounds, we shall have a series of five—

Nitrogen rations.

a. One-twelfth ration: Nitrate of soda, 38 pounds, with 6 pounds of nitrogen.
b. One-sixth ration: Nitrate of soda, 75 pounds, with 12 pounds nitrogen.
c. One-third ration: Nitrate of soda, 150 pounds, with 24 pounds nitrogen.
d. Two-thirds ration: Nitrate of soda, 300 pounds, with 48 pounds nitrogen.
e. Full ration: Nitrate of soda, 450 pounds, with 72 pounds nitrogen.

Of this list, either all or part may be used. Thus on soils or for crops where smaller quantities are in place, *a*, *b*, and *c* could be employed. Where more nitrogen is

wanted, *c*, *d*, and *e* would be better. If, as is not impossible, experience should show that the smaller rations are too small to be useful, it will be a very simple matter to omit them.

Phosphoric acid.—One hundred pounds of a superphopshate with 16 per cent. P_2O_5 is as little as would be often used on an acre, while 600 pounds with 96 pounds of P_2O_5 would be a large dressing. In view of the fact that general experience has led to the employing of much larger quantities of phosphoric acid than of nitrogen, the proportions within this range would be none too large to go with those of nitrogen suggested. Doubtless a series of four rations arranged as below would suffice.

Phosphoric acid rations.

a. One-sixth ration: 100 pounds superphosphate with 16 pounds phosphoric acid.
b. One-third ration: 200 pounds superphosphate with 32 pounds phosphoric acid.
c. Two-thirds ration: 400 pounds superphosphate with 64 pounds phosphoric acid.
d. Full ration: 600 pounds superphosphate with 96 pounds phosphoric acid.

Potash.—Many of the popular fertilizing mixtures are calculated to supply very small quantities of potash, not over 17 pounds per acre, while 200 pounds of muriate of potash are often used for a dressing. Taking these as extremes and dividing as before we shall have—

Potash rations.

a. One-sixth ration: 33 pounds muriate of potash with 17 pounds potash.
b. One-third ration: 67 pounds muriate of potash with 33 pounds potash.
c. Two-thirds ration: 133 pounds muriate of potash with 67 pounds potash.
d. Full ration: 200 pounds muriate of potash with 100 pounds potash.

Putting the above forms together we have rations as follows:

	Nitrate of soda.	Superphosphate.	Muriate of potash.	Nitrogen.	Phosphoric acid.	Potash.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
One-twelfth ration	38	....	....	6	....	....
One-sixth ration	75	100	33	12	16	17
One-third ration	150	200	67	24	32	33
Two-thirds ration	300	400	133	48	64	67
Full ration	450	600	200	72	96	100

DUPLICATION OF TESTS.

A very great, if not the greatest, obstacle to the success of field experiments is the unevenness of soils. The variations in the produce of different plots of apparently uniform land under the same treatment are often very surprising. An experiment in which duplicates agree as closely as could be desired is the exception rather than the rule. Cases in which the differences between plots treated alike are greater than between those treated differently, are, if anything, more common.

To get around this difficulty, numerous devices are employed. One is to test the uniformity of the plots by treating all alike the first year, and, if they vary materially, to either attempt to average duplicates so as to make the differences counterbalance, or to allow for the differences in computing the final results. One serious objection to either of these plans is the uncertainty as to the cause of the variation and to whether it will be constant in succeeding years.

Another plan consists in making the plots long and narrow, so as to equalize the differences. This, though often successful, is not always so. The ideal method would be to test the experimental areas by uniform treatment for a series of years until

temporary causes of irregularity, such as came from manuring, tillage, cropping, &c., were eliminated, and to use for experiment only such as prove to be intrinsically uniform.

Where feasible, this latter plan is certainly to be recommended. But if we are to begin an experiment at once, doubtless the best way is to use small plots and duplicate the trials by using the same materials on several. This duplicating will test the uniformity and reliability of the whole experiment, and give averages which, when no untoward circumstances prevent, are pretty sure to be fairly satisfactory and are often perfectly so.

SIZE OF EXPERIMENTAL PLOTS.

Ordinarily, plots of eight square rods, one-twentieth acre, each, seem as satisfactory as any. In most cases, two plots of one-twentieth would be preferable to one of one-tenth acre. At least, such is the impression left on my mind after looking over the reports of several hundred experiments sent me for examination. Before this experience I was inclined to larger areas, but I have been surprised at the uniformity of small plots, when they are long and narrow. Some of the most satisfactory field experiments have been on plots of only four square rods. It is very common to leave a number of plots unmanured to test the uniformity of the soil, but it is a question whether this purpose is not better served by duplicating manured plots, and using not more than two or three unmanured for an ordinary experiment. Thus, for the nitrogen experiments, the most satisfactory plan I have found has been to leave one unmanured plot on each side of the experimental field, and to frequently duplicate the "basal mixture" of superphosphate and potash salt.

SPACES BETWEEN THE EXPERIMENTAL PLOTS.

Another frequent cause of inaccuracy in field experiments with fertilizers is the extension of the roots of the plants of one plot into the soil of the next one, so that the plants feed upon their neighbors' fertilizers. The roots of corn, for instance, extend laterally several feet, and, unless something is done to prevent, the plants may get so much material that does not belong to them as to vitiate the results of the experiments. The yield on an unmanured plot between two manured ones is often much larger than on another unmanured plot whose plants have not the fertilizers close at hand to draw upon. The best plan to obviate this is to leave unmanured strips between the experimental plot so wide that the roots will not reach across them. The difficulty can be helped, of course, by plowing between the plots deep enough to cut the roots.

NITROGEN EXPERIMENTS.

In planning these experiments we need to consider the questions to be studied, the forms and quantities of nitrogen to be used, and the most fitting arrangement for the experiments. The following details naturally suggest themselves:

A.—Questions especially needing Study.

I. The action of nitrogen in different forms and amounts upon the growth of plants under varying conditions of crop, soil, climate, season, &c.

II. The feeding capacities of different plants as related to nitrogen, *i. e.*, their capacities for providing themselves with nitrogen from natural sources, and for utilizing that furnished in the fertilizers, in so far as these capacities are indicated by effects of the nitrogenous materials upon their growth.

B.—Forms and Amounts of Nitrogen and Nitrogenous Fertilizers.

I. The most important forms of nitrogen are:

1. Nitric acid.
2. Ammonia.
3. Organic nitrogen.

II. Among the kinds of fertilizers containing nitrogen in these forms, the following are important:

1. Nitric acid.
   a. Nitrate of soda.
   b. Nitrate of potash.
2. Ammonia.
   a. Sulphate of ammonia.
3. Organic nitrogen.
   a. Dried blood.
   b. Meat scrap.
   c. Fish scrap and fish guano.
   d. Leather scraps.

III. Quantities, as above named, to wit, "one-twelfth," "one-sixth," "one-third," "two-thirds," and "full rations," or 6, 12, 24, 48, and 72 pounds per acre.

DETAILED PLANS.

In the account of nitrogen experiments above are schedules of the kinds and quantities of fertilizing materials there employed. Judging from the results of past experience, however, those schedules would be improved by slightly altering the quantities so as to make them conform with the rations just named, and by enlarging the list of nitrogenous fertilizers to be tested.

KINDS OF NITROGENOUS FERTILIZERS.

The following will doubtless be to the purpose:

1. For nitric acid, nitrate of soda, 96 per cent. purity, with 16 per cent. nitrogen.
2. For ammonia, sulphate of ammonia, with 21 per cent. nitrogen.
3. For organic nitrogen.
   a. Dried blood (steam dried), with 11 per cent. nitrogen.
   b. Meat scrap, azotin, with 11 per cent. nitrogen.
   c. Fish guano, with 8 per cent. nitrogen.
   d. Leather scraps (finely pulverized), with 7 per cent. nitrogen.
4. For nitric acid, ammonia, and organic nitrogen together, "nitrogen mixture," consisting of nitrate of soda, 16 per cent. nitrogen; sulphate of ammonia, 21 per cent. nitrogen, and dried blood 11 per cent. nitrogen in equal parts, and containing 16 per cent. nitrogen.

QUANTITIES OF NITROGENOUS FERTILIZERS.

We may plan for each nitrogenous fertilizer a "group" with rations, as above suggested. Thus we may have nitrogen groups with quantities per acre as follows:

Nitrogen rations.

	Ration.	Nitrate of soda.		Ration.	Sulphate of ammonia.
		Pounds.			*Pounds.*
Nitrate of soda Group	One-twelfth	38	Sulphate of ammonia Group	One-twelfth	29
	One-sixth	75		One-sixth	57
	One-third	150		One-third	114
	Two-thirds	300		Two-thirds	228
	Full	450		Full	343

	Ration.	Dried blood.		Ration.	Nitrogen mixture.
		Pounds.			*Pounds.*
Dried blood Group	One-twelfth	55	Nitrogen mixture Group	One-twelfth	38
	One-sixth	110		One-sixth	75
	One-third	220		One-third	150
	Two-thirds	440		Two-thirds	300
	Full	660		Full	450

ARRANGEMENT OF THE EXPERIMENTS.

In this way such materials as may be most desirable can be selected for each experiment, and for each a group be used with all or part of the rations suggested. Future experience must show what quantities will be best. Probably, for ordinary crops in the North, the three largest rations will be well. In the South, for cotton, very likely the smaller will be preferable. At any rate, this flexibility of plan allows fair latitude of detail, and at the same time secures the uniformity needed for the tabulation and comparison of different experiments.

In some cases it will be desirable to use the nitrogenous fertilizers alone. In the majority of cases, however, the full effect of the nitrogen will not be manifested unless some other materials are added. Generally speaking, the experiment will be most satisfactory with "complete fertilizers," such as can be made by adding the nitrogenous materials to a mixture of superphosphate and potash salt, which may be designated as "mineral fertilizers" or "mixed minerals." For these, the two-thirds rations, 400 pounds of superphosphate and 133 pounds of muriate of potash, will probably be adapted to a larger proportion of the soils and crops than the mixture of 300 pounds of superphosphate and 150 pounds of muriate of potash, used in the former nitrogen experiments. Taking the basal mixture named, and adding the several rations of nitrate of soda, we shall have a "Nitrate of Soda Group" of five mixtures, each mixture containing the "mixed minerals" with a nitrate of soda ration as below:

Nitrate of Soda Group:

Mixed minerals with nitrate of soda, one-twelfth ration.
Mixed minerals with nitrate of soda, one-sixth ration.
Mixed minerals with nitrate of soda, one-third ration.
Mixed minerals with nitrate of soda, two-thirds ration.
Mixed minerals with nitrate of soda, full ration.

The amount per acre and the percentages of the several ingredients in the nitrogen mixture group, for instance, would be as follows:

Nitrogen mixture group.	Fertilizing materials.			Ingredients.					
	Superphosphate, pounds per acre.	Muriate of potash, pounds per acre.	Nitrogen mixture, pounds per acre.	Phosphoric acid, pounds per acre.	Potash, pounds per acre.	Nitrogen, pounds per acre.	Phosphoric acid, per cent.	Potash, per cent.	Nitrogen, per cent.
One-twelfth ration	400	133	38	64	67	6	11.2	11.7	1.5
One-sixth ration	400	133	75	64	67	12	10.5	11.0	2.0
One-third ration	400	133	150	64	67	24	9.3	9.8	3.5
Two-thirds ration	400	133	300	64	67	48	7.6	8.0	5.8
Full ration	400	133	450	64	67	72	6.5	6.8	7.3

PRELIMINARY GROUP.

The experiment will be much more satisfactory if we know the effects of the superphosphate, potash, salt, and nitrogenous materials separately, and, inferentially, the capacity of the soil to supply the phosphoric acid and potash as well as the nitrogen. To this end we may use the materials separately, and two by two, as has been done in previous experiments, and is shown in the schedule beyond. In the experiments described above the nitrogen of the preliminary groups has been supplied in either nitrate of soda or "nitrogen mixture." Though experience has shown very little difference, probably the mixture will be the safer, and accordingly it is here recommended.

As urged above, the many sources of error in field experiments make duplicates very important. This may be effected by repeating the nitrogen groups, in which opportunity is taken to test the different forms of nitrogen, and by putting the mixed minerals on each side of each nitrogen group, thus testing the uniformity of the soil, replacing the unmanured plots, and showing more accurately the effects of the nitrogen.

To recapitulate briefly, our experimental fertilizers, as thus planned, will be arranged in groups, thus:

Partial fertilizers....	Preliminary Group. Each by itself, and two by two.	Thus testing the effects of ingredients separately and capacity of soil to supply them.
Complete fertilizers..	Nitrate of soda Group. Nitrogen as nitric acid in nitrate of soda. Sulphate of ammonia Group. Nitrogen as ammonia in sulphate of ammonia. Dried blood Group. Nitrogen as organic nitrogen in dried blood. Nitrogen mixture Group. Nitrogen in the three forms named above.	Nitrogen in one-twelfth, one-sixth, one-third, two-thirds, and full rations.

Other groups containing meat scrap, fish guano, Peruvian guano, leather scrap, &c., can be employed at the discretion of the experimenter. When desired, as may be the case with cotton, for instance, half the quantities may be used, or the same quantities distributed over double the area. The preliminary groups can be omitted if necessary, the nitrogen groups used without the basal mixture, and a smaller list of rations used in each group, as may be desirable in each case. Two nitrogen sets, which can be obtained ready for use, are described beyond.

PHOSPHORIC ACID EXPERIMENTS.

In devising plans for these experiments we have to consider what questions are to be studied and what compounds of phosphoric acid are to be employed.

A.—Questions to be studied.

The following may be regarded, at the outset at least, as among the more important:

I. The action of phosphoric acid in different forms and amounts upon the growth of plants under different conditions of crop, soil, climate, season, &c., *e. g.*,

1. Soluble *vs.* precipitated.
2. Soluble *vs.* insoluble.
3. Effects of fineness of pulverization upon the availability of insoluble phosphoric acid in bone, rock phosphate, &c.
4. Bone *vs.* mineral phosphate.
5. Raw bone *vs.* boiled bone; *i. e.*, bone from which gelatine has been extracted.

II. The feeding capacities of different plants as related to phosphoric acid, *i. e.*, their capabilities of availing themselves of the supplies of phosphoric acid at their disposal in the soil, and in fertilizers, in so far as their capabilities are indicated by the observed effects of the phosphoric acid compounds.

B.—Forms and amounts of phosphoric acid and phosphatic compounds.

The following list seems complete enough for the present purpose:

I. Forms of phosphoric acid:

1. Soluble.
2. Precipitated.
3. Insoluble.

II. Kinds of phosphatic compounds:

1. Bone.
    a. Raw.
    b. Steamed.
    c. Bone black.
    d. Bone ash.
2. Phosphatic guanos.
    a. Curaçoa, &c.

3. Mineral or rock phosphate.
    - *a.* South Carolina.
    - *b.* Navassa.
    - *c.* Apatite, &c.

III. Grades of fineness: The grades of fineness will naturally depend upon what the market affords. We might use, for instance:

1. Coarse.
2. Medium.
3. Fine.

IV. Quantities of phosphoric acid:

Each of the several forms may be used in different "rations," the several rations making a group, as in the nitrogen experiments.

DETAILED PLANS.

For the specific materials to furnish the phosphoric acid in the soluble and precipitated forms, the following are perhaps as well fitted for the purpose as any. Of course others will suggest themselves.

1. Soluble phosphoric acid:
    - *a.* Dissolved bone black with 16 per cent. P_2O_5.
    - *b.* High-grade superphosphate with 32 per cent. P_2O_5.

  Of the above, perhaps (*a*) will serve best to begin with.

2. Precipitated phosphoric acid. This may consist of—
    - *a.* High-grade superphosphate with equal weights of chalk, making a preciptated phosphate with 16 per cent. P_2O_5.
3. Insoluble phosphoric acid. For this, bone, phosphatic guanos, and mineral or rock phosphates will be in order. Bone and South Carolina phosphate are perhaps the most important at present:
    - *a.* Fine bone dust (mesh, 40.) from steamed or raw bone with 25 per cent. P_2O_5.
    - *b.* South Carolina phosphate with 25 per cent. P_2O_5.

QUANTITIES OF PHOSPHORIC ACID.

As already suggested, we may arrange for each of the phosphatic compounds a group of four rations. Below are examples with quantities per acre:

	Ration.	Dissolved bone black.		Ration.	Precipitated superphosphate.
		Pounds.			*Pounds.*
SUPERPHOSPHATE GROUP.	*a.* One-sixth	100	PRECIPITATED PHOSPHATE GROUP.	*a.* One-sixth	100
	b. One-third.....	200		*b.* One-third.....	200
	c. Two-thirds...	400		*c.* Two-thirds...	400
	d. Full..........	600		*d.* Full..........	600

	Ration.	South Carolina superphosphates.		Ration.	Steamed bone.
		Pounds.			*Pounds.*
SOUTH CAROLINA SUPERPHOSPHATE GROUP.	*d.* One-sixth	133	STEAMED BONE GROUP.	*a.* One-sixth	67
	b. One-third.....	267		*b.* One-third.....	133
	c. Two-thirds...	533		*c.* Two-thirds...	267
	a. Full..........	800		*d.* Full..........	400

The effects of fineness of pulverization may be tested by such groups as these:

	Grade of fineness.	Ground bone.		Grade of fineness.	Phosphate.
		Pounds.			*Pounds.*
FINE, MEDIUM, AND COARSE BONE DUST GROUP.	Fine	400	FINE, MEDIUM, AND COARSE S. C. PHOSPHATE GROUP.	Fine	400
	Medium	400		Medium	400
	Coarse	400		Coarse	400

The details of quantities per acre and percentages of the Superphosphate Group, for instance, will be:

SUPERPHOSPHATE GROUP.	Fertilizing materials.			Ingredients.					
	Nitrogen mixture, pounds per acre.	Muriate of potash, pounds per acre.	Superphosphate, pounds per acre.	Nitrogen, pounds per acre.	Potash, pounds per acre.	Phosphoric acid, pounds per acre.	Nitrogen, per cent.	Potash, per cent.	Phosphoric acid, per cent.
A. One-sixth ration	150	133	100	24	67	16	6.3	17.3	4.2
B. One-third ration	150	133	200	24	67	32	5.0	13.9	6.7
C. Two-thirds ration	150	133	400	24	67	64	3.5	9.8	9.4
D. Full ration	150	133	600	24	67	96	2.7	7.6	10.9

That is to say, the Superphosphate Group would thus consist of four mixtures. Each of these mixtures will contain a "basal mixture" with nitrogen and potash each in $\frac{2}{3}$ ration. To this basal mixture the superphosphate is added in successive amounts, from "one-sixth ration" to "full ration," or from 16 to 96 pounds per acre.

SULPHATE OF LIME GROUP.

Since more or less of the effect of the superphosphate may be due to its sulphate of lime, a check trial with plaster as provided in the schedule on page 31 may be advisable.

The explanation of the nitrogen experiment will apply, *mutatis mutandis*, to the phosphoric acid experiment. The idea is to so arrange the materials that each experimenter may select groups or parts of groups at his discretion and thus make up such an experiment as will be most to the purpose in the conditions under which he works.

The following list of materials and groups includes perhaps the most important, and suggests a schedule of experimental fertilizers:

Partial Fertilizers...	Preliminary Group, each by itself, and two by two.	Thus testing the effects of ingredients separately, and capacity of soil to supply them.
Complete Fertilizers.	Soluble phosphoric acid Group. Precipitated phosphoric acid Group. Insoluble phosphoric acid Group. Steamed bone. Insoluble phosphoric acid Group. Raw bone. Insoluble phosphoric acid Group. S. C. phosphate. Sol., Precip., and Insol. Phos. acid Group. S. C. superphosphate. Etc., etc.	Phosphoric acid in one-sixth ration, one-third ration, two-thirds ration, and full ration.
	Raw bone Group. South Carolina phosphate Group. Etc., etc., etc.	Different grades of fineness.

SCHEDULES FOR EXPERIMENTS.

While experimenters will arrange their experiments at discretion, it has seemed to me desirable to suggest schedules, and, if practicable, to make arrangements to assist them in procuring the materials with the least trouble and expense. I have, therefore, drawn up schedules for three sets of experimental fertilizers, as follows:

The first, "*Nitrogen Set No.* 1," is nearly the same as used by a number of gentlemen last season. Nitrogen is supplied as nitric acid, ammonia, and organic nitrogen, in three groups with three rations, ⅓, ⅔, and full ration, in each. The set requires 18 plots for the fertilizers, which, with two unmanured, would make 20 plots, or, with one-twentieth acre plots, one acre of land, for the experiment. With spaces between the plots a larger area will be needed.

NITROGEN SET NO. 1.

Materials.			Amounts. Acre set—for one-twentieth acre plots.	Amounts. Two-acre set—for one-tenth acre plots.
			Pounds.	*Pounds.*
Preliminary Group	1.	Nitrate of soda, one-third ration	7.5	15.0
	2.	Superphosphate	20.0	40.0
	3.	Muriate of potash	6.7	13.3
	4.	Nitrate of soda, one-third ration	7.5	15.0
		Superphosphate	20.0	40.0
	5.	Nitrate of soda, one-third ration	7.5	15.0
		Muriate of potash	6.7	13.3
	6.	Superphosphate, } Mixed minerals.	20.0	40.0
		Muriate of potash } Mixed minerals.	6.7	13.3
Nitrate of soda Group	7.	Mixed minerals, as No. 6	26.7	53.3
		Nitrate of soda, one-third ration	7.5	15.0
	8.	Mixed minerals, as No. 6	26.7	53.3
		Nitrate of soda, two-thirds ration	15.0	30.0
	9.	Mixed minerals, as No. 6	26.7	53.3
		Nitrate of soda, full ration	22.5	45.0
	6*a*.	Mixed minerals, as No. 6	26.7	53.3
Sulphate of ammonia Group.	10.	Mixed minerals, as No. 6	26.7	53.3
		Sulphate of ammonia, one-third ration	5.6	11.3
	11.	Mixed minerals, as No. 6	26.7	53.3
		Sulphate of ammonia, two-thirds ration	11.3	22.5
	12.	Mixed minerals, as No. 6	26.7	53.3
		Sulphate of ammonia, full ration	16.8	33.7
	6*b*.	Mixed minerals, as No. 6	26.7	53.3
Dried blood Group	13.	Mixed minerals, as No. 6	26.7	53.3
		Dried blood, one-third ration	11.0	22.0
	14.	Mixed minerals, as No. 6	26.7	53.3
		Dried blood, two-thirds ration	22.0	44.0
	15.	Mixed minerals, as No. 6	26.7	53.3
		Dried blood, full ration	33.0	66.0
	6*c*.	Mixed minerals, as No. 6	26.7	53.3

The following, "*Nitrogen Set No.* 2," is simpler, containing only the preliminary group, and a nitrogen mixture group with five rations, and one extra "mixed minerals." It has the advantage of greater simplicity, and of testing the effects of smaller quantities of nitrogen, but has the disadvantage of not duplicating the nitrogen tests. It can be greatly improved by duplicating the "nitrogen mixture" group, which, with an extra "mixed minerals," will make 18 fertilizers. With one-twentieth acre plots this would require an acre, and make an excellent experiment.

NITROGEN SET NO. 2.

Materials.			Amounts. Set—for one-twentieth acre plots.	Amounts. Set—for one-tenth acre plots.
			Pounds.	*Pounds.*
Preliminary Group	1.	Nitrogen mixture, one-third ration	7.5	15.0
	2.	Superphosphate	20.0	40.0
	3.	Muriate of potash	6.7	13.3
	4.	Nitrogen mixture, one-third ration	7.5	15.0
		Superphosphate	20.0	40.0
	5.	Nitrogen mixture, one-third ration	7.5	15.0
		Muriate of potash	6.7	13.3
	6.	Superphosphate	20.0	40.0
		Muriate of potash	6.7	13.3
Nitrogen mixture Group.	7.	Mixed minerals	26.7	53.3
		Nitrogen mixture, one-twelfth ration	1.9	3.8
	8.	Mixed minerals	26.7	53.3
		Nitrogen mixture, one-sixth ration	3.7	7.5
	9.	Mixed minerals	26.7	53.3
		Nitrogen mixture, one-third ration	7.5	15.0
	10.	Mixed minerals	26.7	53.3
		Nitrogen mixture, two-thirds ration	15.0	30.0
	11.	Mixed minerals	26.7	53.3
		Nitrogen mixture, full ration	22.5	45.0
	6*a*.	Mixed minerals	26.7	53.3

The following specifications are intended for use in ordering the fertilizers:

Specifications for nitrogen sets.—Materials to be weighed and mixed with greatest possible care and accuracy, put in bags, and each bag furnished with a label stating number and contents per schedule. *Minimum* percentages as follows: Nitrate of soda, 16 per cent. nitrogen; sulphate of ammonia, 21 per cent. nitrogen; dried blood, 11 per cent. nitrogen; superphosphate (dissolved bone black) 15 per cent. soluble and 16 per cent. total phosphoric acid; muriate of potash, 50 per cent. potash.

PHOSPHORIC ACID SET.

This tests the action of soluble phosphoric acid, in dissolved bone black, precipitated phosphoric acid in a mixture of high grade superphosphate from bone and chalk, and insoluble phosphoric acid in bone from which the larger part of the organic matter has been removed. A sulphate of lime group is added as a test of the effect of the sulphuric acid and lime of the superphosphates. This includes 25 fertilizers, which with two unmanured plots would require 27 plots, or, if each plot is one-twentieth acre, a little over $1\frac{1}{3}$ acres, and more if unmanured strips are left between the rows. The set can be reduced to 21 by omitting the sulphate of lime group, and to 18 by using only three rations in each phosphoric acid group.

PHOSPHORIC ACID SET.

Group	Plot	Materials	Amounts: Regular size for one-twentieth acre plots.	Amounts: Double size for one-tenth acre plots.
			Pounds.	*Pounds.*
Preliminary Group	A.	Nitrogen mixture	7.5	15.0
	B.	Superphosphate	20.0	40.0
	C.	Muriate of potash	6.7	13.3
	D.	Nitrogen mixture	7.5	15.0
		Superphosphate	20.0	40.0
	E.	Muriate of potash	6.7	13.3
		Superphosphate	20.0	40.0
	F.	Nitrogen mixture. } Basal mixture	7.5	15.0
		Muriate of potash } Basal mixture	6.7	13.3
Soluble phosphoric-acid Group.	A.	Basal mixture	14.2	28.3
		Dissolved bone black	5.0	10.0
	B.	Basal mixture	14.2	28.3
		Dissolved bone black	10.0	20.3
	C.	Basal mixture	14.2	28.3
		Dissolved bone black	20.0	40.0
	D.	Basal mixture	14.2	28.3
		Dissolved bone black	30.0	60.0
	F*a*.	Basal mixture	14.2	28.3
Precipitated phosphoric-acid Group.	A.	Basal mixture	14.2	28.3
		Precipitated phosphate	5.0	10.0
	B.	Basal mixture	14.2	28.3
		Precipitated phosphate	10.0	20.0
	C.	Basal mixture	14.2	28.3
		Precipitated phosphate	20.0	40.0
	D.	Basal mixture	14.2	28.3
		Precipitated phosphate	30.0	60.0
	F*b*.	Basal mixture	14.2	28.3
Steamed bone Group.	A.	Basal mixture	14.2	28.3
		Bone dust	5.0	10.0
	B.	Basal mixture	14.2	28.3
		Bone dust	10.0	20.0
	C.	Basal mixture	14.2	28.3
		Bone dust	20.0	40.0
	D.	Basal mixture	14.2	28.3
		Bone dust	30.0	60.0
	F*c*.	Basal mixture	14.2	28.3
Sulphate of lime Group.	A.	Basal mixture	14.2	28.3
		Plaster	3.8	7.5
	B.	Basal mixture	14.2	28.3
		Plaster	7.5	15.0
	C.	Basal mixture	14.2	28.3
		Plaster	11.3	22.5
	F*d*.	Basal mixture	14.2	28.3

Besides the above set, groups like the following may be employed:

Materials.			Amounts. Regular size for one-twentieth acre plots.	Amounts. Double size for one-tenth acre plots.
			Pounds.	*Pounds.*
South Carolina superphosphate Group.	A.	Basal mixture	14.2	28.3
		South Carolina superphosphate	6.7	13.3
	B.	Basal mixture	14.2	28.3
		South Carolina superphosphate	13.3	26.7
	C.	Basal mixture	14.2	28.3
		South Carolina superphosphate	26.7	53.4
	D.	Basal mixture	14.2	28.3
		South Carolina superphosphate	40.0	80.0
South Carolina phosphate Group.	A.	Basal mixture South Carolina phosphate	14.2	28.3
	B.	Basal mixture South Carolina phosphate	14.2	28.3
	C.	Basal mixture South Carolina phosphate	14.2	28.3
	D.	Basal mixture South Carolina phosphate	14.2	28.3
Steamed bone group.	A.	Basal mixture	14.2	28.3
		Steamed bone	5.0	10.0
	B.	Basal mixture	14.2	28.3
		Steamed bone	10.0	20.0
	C.	Basal mixture	14.2	28.2
		Steamed bone	20.0	40.0
	D.	Basal mixture	14.2	28.3
		Steamed bone	30.0	60.0
Fine, medium, and coarse bone Group.	A.	Basal mixture	14.2	28.3
		Ground bone (fine)	20.0	40.0
	B.	Basal mixture	14.2	28.3
		Ground bone (medium)	20.0	40.0
	C.	Basal mixture	14.2	28.3
		Ground bone (coarse)	20.0	40.0
Fine, medium, and coarse South Carolina phosphate Group.	A.	Basal mixture	14.2	28.3
		South Carolina phosphate (fine)	20.0	40.0
	B.	Basal mixture	14.2	28.3
		South Carolina phosphate (medium)	20.0	40.0
	C.	Basal mixture	14.2	28.3
		South Carolina phosphate (coarse)	20.0	40.0

Specifications for fertilizers of phosphoric acid set: Materials to be put up with greatest care in bags, with labels stating contents. Minimum percentages as follows: Nitrogen mixture and muriate of potash as in nitrogen experiment. Superphosphate (dissolved bone black) with 15 per cent. soluble, and 16 per cent. total P_2O_5. Precipitated phosphate to consist of high grade superphosphates 32 per cent. and chalk in equal parts, and to contain 16 per cent. P_2O_5. Other materials to be of good average quality.

CROPS TO BE EXPERIMENTED UPON.

The kind of crop will, of course, be selected by the experimenter. Experiments are needed upon all our ordinary crops, but especially on wheat, barley, rye, oats, corn, sorghum, grass, clover, onions, potatoes, roots, and, in the South, sugar cane and cotton.

The following is a copy of directions for experiments suggested to accompany the above plans:

CO-OPERATIVE EXPERIMENTS WITH FERTILIZERS.

Directions for Special Nitrogen and Phosphoric Acid Experiments.

GENERAL SUGGESTIONS.

1. It is important to have plans complete and clearly in mind, and everything ready before starting. Proper plans at the outset; uniform soil, which should also be "worn-

out" if its permanent capacity for production and the true effects of the fertilizers are to be tested; plots of proper size, shape, and accurately laid out; right application of the fertilizers; good seed; careful measurement of crops; full notes of details; and careful observation of the effects of the fertilizers on succeeding crops, are essential to the best results.

CHOICE OF EXPERIMENTAL FIELD.

2. Uniformity of soil is of the utmost importance. There will be more or less variation in different parts of the same field at best. The unevenness is sometimes so great as to spoil the experiment. The less the variation the more reliable will be the results. Level land should be chosen if practicable, but if it be sloping let the plots run up and down the ascent, so that wash by rains will not transfer the materials from one plot to another.

"WORN-OUT" SOILS FOR THE TESTS.

3. The object is to learn what can be done by the soil with its "natural strength." A store of plant food, either accumulated by natural processes or left over from previous manuring, would obscure the action of the fertilizers, and render the experiments indecisive.

DIMENSIONS OF PLOTS.

4. It is well to make the plots long and narrow, so as to compensate as far as possible for the unevenness of the soil. If the soil is even, small, short plots will do, but generally it will not be even, and long strips are, therefore, safer. To this end let the whole area be as long and narrow as convenient, and the plots run lengthwise through it. If the seed is to be planted in rows the length can be adapted to the distance of the rows apart. If this space is less than two and one-half feet, it will be best to leave an unmanured row between each two strips. In general, an unmanured strip, three feet wide, or wider, should be left between each two plots, so as to prevent the crop of one from being affected by the manure of another. If this is too inconvenient, the next best plan will probably be to cultivate between the rows deep enough to cut the roots and prevent them from feeding on their neighbor's fertilizers.

Strong stakes should be driven firmly into the ground at the boundaries of the plots and not allowed to be knocked over or plowed up.

The following figures will be of service in calculating the dimensions of the experimental plots and field.

To calculate the size of plot of 1-20 acre, find in the left-hand column "Width," the figure for the width decided upon, the opposite figure in the right-hand column will represent the length. Or, given the length in the right-hand column, the opposite figure in the left-hand column will be the width. For 1-10-acre plots, take of course double the given length for same width, or double the given width for same length.

ONE-TWENTIETH ACRE PLOTS, WIDTH AND LENGTH.

Assumed width.	Required length.	Assumed width.	Required length.
Rods:	*Feet. Rods. Ft.*	Rods:	*Feet. Rods. Ft.*
One-third	396 = 24 00	Two-thirds	198 = 12 00
Two-fifths	330 = 20 00	Three-fourths	176 = 10 11
One-half	264 = 16 00	Four-fifths	165 = 10 00
Three-fifths	220 = 13 5¼	One	132 = 8 00
Feet:		Feet:	
6	363 = 22 00	11½	189 = 11 8
6½	335 = 20 5	12	182 = 11 00
7	312 = 18 14	12½	174 = 10 9
7½	291 = 17 10	13	168 = 10 3
8	273 = 16 8	13½	161 = 9 13
8½	257 = 15 9	14	155 = 9 7
9	242 = 14 10	14½	150 = 9 2
9½	230 = 15 15	15	145 = 8 13
10	218 = 13 4	15½	141 = 8 8
10½	208 = 12 9	16	136 = 8 4
11	198 = 12 00	16½	132 = 8 00

For an area of one acre, 160 square rods, 10 x 16 rods will be good dimensions. This will make twenty plots—each ½ rod x 16 rods = 8 sq. rods, = 1-20 acre. Unmanured strips between the plots will, of course, increase the size of the experimental field.

FERTILIZERS WELL DIFFUSED THROUGH SOIL.

5. In general, it is well to apply the fertilizers broadcast. They may, however, be put in the hill or drill, *provided they are well diffused through the soil* To accomplish this, it is well to mix them with several times their bulk of earth, saw-dust, or other diluent, before using. The important points are, that they be:

1st. Applied evenly over the plots where they belong and not allowed to get outside.

2nd. Well distributed through the soil. When the seed is in hills or drills an excellent plan is to spread the fertilizers over a space, say two feet wide, along the row.

UNMANURED PLOTS AND DUPLICATE MANURED PLOTS FOR COMPARISON.

6. Unmanured plots will, of course, be left for tests of capacity of the soil. Both these and the duplicate "mixed minerals" of the nitrogen experiment or "basal mixtures" of the phosphoric acid experiment, will test the uniformity of the soil.

REPORTS.

7. Blanks will be forwarded to experimenters for recording and reporting details as to soil, culture, weather, and products. The observations and notes made during the growth of the plants will greatly enhance the value of the reports.

PLAN OF EXPERIMENTAL FIELD.

The plan herewith shows a fitting arrangement for the "Nitrogen Experiment No. 1, 1882," and illustrates how others may advantageously be planned.

NITROGEN EXPERIMENT.

ARRANGEMENT OF EXPERIMENTAL FIELD.

With "Acre set." Each plot 1-20 acre.
Whole field one acre.
With "Two-acre set." Each plot 1-10 acre.
Whole field two acres.

Or more with unmanured strips between each two plots.

	0	No manure.
Preliminary Group.	1	Nitrate of soda.
	2	Superphosphate.
	3	Muriate of potash.
	4	Nitrate of soda and superphosphate.
	5	Nitrate of soda and muriate of potash.
	6	Superphosphate and muriate of patash. "Mixed minerals."
Nitric Acid Group.	7	Mixed minerals plus nitrate of soda. One-third ration.
	8	Mixed minerals plus nitrate of soda. Two-thirds ration.
	9	Mixed minerals plus nitrate of soda. Full ration.
	6*a*	Mixed minerals. Duplicate of No. 6.
Ammonia Group.	10	Mixed minerals plus sulphate of ammonia. One-third ration.
	11	Mixed minerals plus sulphate of ammonia. Two-thirds ration.
	12	Mixed minerals plus sulphate of ammonia. Full ration.
	6*b*	Mixed minerals. Duplicate of No. 6.
Organic Nitrogen Group.	13	Mixed minerals plus dried blood. One-third ration.
	14	Mixed minerals plus dried blood. Two-thirds ration.
	15	Mixed minerals plus dried blood. Full ration.
	6*c*	Mixed minerals. Duplicate of No. 6.
	00	No manure.

APPENDIX.

EXPLANATION OF TABLES.

It has seemed to me that the best way to dispose of the very large mass of materia which the reports of the experiments make up, will be to arrange it as far as possible in tabular form; and to put the larger and more detailed tables by themselves, as is attempted here.

TABLE I.—This table gives the results of experiments with corn described above. As was explained, the details regarding soil, culture, weather, &c., as reported by the experimenters, are given beyond.

TABLE II gives results of experiments with potatoes on the plan of those with corn of Table I.

TABLE III gives similar results of experiments with corn, cotton, clover, and potatoes. It will be noticed that these experiments were all made in the year 1881, upon a schedule slightly different from that of Tables I and II. The differences in these schedules have all been explained above.

TABLES IV to IX.—These tables include what we have called the "general experiments" (that is, those that were made primarily as soil tests). As space scarcely permits the printing of all the details as to the soil, culture, weather, &c., which were given by the experimenters in their reports, some principal data have been tabulated along with the figures for produce. Table IV gives experiments with corn in 1878; Table V, those with potatoes in 1878; Tables VI and VII include the experiments of 1879; Tables VIII and IX those of 1880.

It will be noted that no tables are given for the general experiments of 1881. I have felt that those are sufficient for their purpose, and have taken no pains to see to a report of the general experiments since 1880. As I look over the matter now, however, I am by no means certain that it would not have been eminently desirable, had my other engagements allowed, to collate and put in print the results obtained in 1881. Still, it has been my idea from the outset, that the experiments should be made gradually to assume a more and more scientific character; and in accordance with that, have, in the latter season, paid less heed to the general and more to the special experiments.

TABLE X.—This table is intended to show (1) the regularity and irregularity of the action of the different materials; (2) the specific effects of the substances furnishing nitrogen, phosphoric acid, potash, and plaster, in the different plots of each experiment. Full explanations may be found in the portion of the article which treats of this subject.

TABLE XI gives the figures selected from Table X, and includes experiments whose results were so free from the impairments due to climate, season, culture, and especial irregularities of soil, as to make them of a special value in illustrating the specific effects of the different materials, and thus throwing light upon the feeding capacities of plants.

TABLE XII gives partial averages of results of the experiments of 1878 to 1881, that is, they include several plots of the general experiments, and the similar plots of the special ones.

TABLE XIII recapitulates the results of the special nitrogen experiments.

Following Table XIII is a condensed statement of the details of the special nitrogen experiments as regards soil, culture, cropping, &c.

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EXE EFFECTS OF DIF

Potash and phosphoric acid (l, two-thirds, and fu

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No. of plot.	FERTILIZER Classification.	Kinds	C. '80. Good.	Poor.	Total.
			Bu.	*Bu.*	*Bu.*
0	....	0. No manure	18. 7	3. 5	22. 2
1	GROUP I. Valuable ingredients, singly.	1. Nitrogen n	16. 8	3. 3	20. 1
2		2. Superphos	41. 6	1. 6	43. 2
3		3. Muriate of	20. 2	4. 5	24. 7
4	GROUP II. Valuable ingredients, two by two.	4. Nitrate of s; Superphos	41. 8	3. 3	45. 1
5		5. Nitrate of s; Muriate of	18. 4	5. 6	24. 0
6		6. Superphos; Mur. pot., 1	50. 4	2. 4	52. 8
7	GROUP III. Nitrogen (as nitrate of soda) in different proportions.	7. Mixed min; Nitrate of s	48. 0	2. 0	50. 0
8		8. Mixed min; Nitrate of s	50. 9	3. 1	54. 0
9		9. Mixed min; Nitrate of s	52. 9	3. 3	56. 2
6*a*	....	6*a*. Mixed min.	......	......	......
00	....	00. No manure	34. 4	3. 4	37. 8
10	GROUP IV. Nitrogen in mixture, in different proportions.	10. Mixed min; Nitrogen ..	46. 4	. 8	47. 2
11		11. Mixed min; Nitrogen n	47. 2	1. 6	48. 8
12		12. Mixed min; Nitrogen n	49. 1	1. 8	50. 9
6*b*	....	6*b*. Mixed min	......	......	......
13	GROUP V. Nitrogen, ⅔ ration, in different combinations.	13. Mixed min; Sulphate o	49. 6	1. 6	51. 2
14		14. Mixed min; Dried bloo	50. 4	1. 6	52. 0
15		15. Peru. guan; Muriate of	49. 1	1. 0	50. 1
16	....	16. Mixed min	49. 6	2. 7	52. 3
17	....	17. Farm man	......	......	......
000	....	000. No manure	......	......	......

(1) The "nitrogen mixture" consisted of nitra 48 lbs. per acre of phos
phosphoric acid and 75 lbs. of "actual potash" pe able manure, well cur

FIELD EXPERIMENT WITH FERTILIZERS, 1879.

ONE GREAT WANT OF OUR AGRICULTURE IS CLOSER STUDY AND OBSERVATION BY FARMERS.

Name of experimenter, *William C. Atwood.*
ADDRESS, P. O., *Watertown*, COUNTY, *Litchfield*, STATE, *Conn.*

The experimenter is requested to fill out this report as fully and accurately as he can, making each entry therefor (in note-book or otherwise) punctually, and trusting nothing to subsequent recollection. For explanations see pamphlet, noting especially pages 13–17. Further particulars than suggested here will be useful, and are requested. This blank is, as you see, prepared with some care. Will not the usefulness to others, as well as to yourself, make it worth your while to devote the needed time and thought to fill it well? Please reserve one copy of this for your own use, and, if practicable, send the other in early in the autumn.

DESCRIPTION OF SOIL.

SPECIFY: SITUATION—upland, lowland, level or hilly, &c. KIND—clay, clayey loam, loam, sandy loam, sandy, gravelly, stony, calcareous (lime), color, much or little vegetable matter, &c. TEXTURE—light, loose, heavy, compact, drained or not, &c. Add other details as they may occur to you.

Situation—*Upland, rolling, slightly inclined to north.*
Kind—*Yellowish sandy loam with considerable vegetable matter, producing heavy growth of common sorrel. No signs of lime.*
Texture—*Light, loose. In my opinion no underdraining desirable.*
Dry or wet—*Medium, excellent rye land in dry seasons.*
Depth of surface soil—*12 to 18 inches.*
Character of subsoil—*Gravelly clay to iron rust hard pan.*
On the whole, for what crop is the soil best suited, and what yields do you usually obtain?—*Contiguous land with 8 cords per acre of good barn manure has yielded 70 bushels of shelled corn per acre, and the year following, with no additional fertilizers, 50 bushels of oats.*
Other remarks—*This field is somewhat remote from my home farm and so situated as to make it impracticable to haul barn manure so far, up a long hill.*

PREVIOUS TREATMENT AND YIELD.

Previous to 1876—*This plot had no manure during my acquaintance with it, sixteen years. It had been used for pasture until, owing to the fact that the stock, cows, were housed at night, it had become somewhat impoverished.*

	1876.	1877.	1878.
Kind of manure	*Dung*	*Nothing*	*Nothing.*
Amount per acre*			
Kind of crop	*Pasturage*	*Buckwheat*	*Rye.*
Amount per acre*			*16 bushels, excellent quality.*

The rye in 1878 was, I think, the finest I ever saw. What did it? Poor husbandry?

* Near as can be estimated.

DESCRIPTION—CONTINUED.

WEATHER DURING EXPERIMENT.

Warm or cold, wet or dry, during each month and season as a whole. Give times of rains or drought.
April—*Cold and wet, land could not be plowed until May.*
May—*1st to 15th cold and quite wet; rest of month warmer. No showers.*
June—*Good growing weather, favorable for corn. Occasional warm showers.*
July—*First week hot and dry. Second cooler. One good shower. Third and fourth weeks excellent corn weather.*
August—*Excellent weather for development of corn crop.*
On the whole what was the character of the season?—*Not the very best, but second only to 1878 since 1870.*

FERTILIZERS—HOW APPLIED.*

Planted in drills 40 inches apart and 8 to 12 inches from plant to plant. I usually plant in drills 3 feet 10 inches apart, applying some kind of fertilizer along the drills so as to cover a strip 12 to 20 inches wide. In this case I aimed to so incorporate the fertilizer with the soil as to avoid injury to the seed. By passing over the ground twice and supplying half of the fertilizer each time with the hand, it was evenly scattered, then raked in carefully so as not to obscure the marks and yet bring some of the fertilizer into the drills well incorporated with earth. Expecting limited returns from some, I made the drills closer together as above, but left strips 5 feet wide between the plots to separate the fertilizers well.

METHOD OF SOWING OR PLANTING, TILLAGE, &c.

About May 1, plowed the acre about 4 inches deep with a cut that turned under completely all the rye stubble and sorrel. Two weeks later plowed again 6 inches deep, leaving sorrel and stubble still covered. During three successive hots days harrowed thoroughly once each day, then smoothing with light brush drag and laid out the plots. Fertilizers were applied and May 19 corn planted, two kernels in a place (one for the crop and one for intruders of various sorts, but thinned in hoeing to one in a place), 10 inches apart and properly covered with the hoe. Stakes then set and labels attached. Cultivated and hoed three times.

OTHER DETAILS AND REMARKS.

I planted late owing to frost, which for some reason unknown to me remained in the field long after adjacent fields had been plowed.

In estimating the dry weight of fodder as compared with actual half-dry weight, I have made an allowance of about 33 per cent., thus giving the advantage to partially and wholly unmanured plots, as all such were less ripe than the others at harvesting. In my estimate of values I concluded to offset the better quality of grain in the manured, against the better quality of fodder in the unmanured plots, thus giving them another small advantage.

I had no expectation of a crop on such land as I have chosen for my experiment without manure, or I should have entered one or two more unmanured plots.

Using a dressing of 40 cords of stable manure and 100 bushels choice compost with plaster and ashes as a top dressing, hoeing three times and weeding once, the whole costing about $350, I obtained 139.3 bushels of shelled corn to the acre. The same land without manure has since yielded as follows: First year, 410 bushels of potatoes; second, 225 bushels oats; third to the thirteenth large crops of hay, all estimated at $1,144.

* With other details, give width of unmanured strips, if any, between manured plots.

TABLE II.—SPECIAL NITROGEN EXPERIMENTS.

Effects of nitrogenous fertilizers upon potatoes and oats.

Potash supplied at rate of about 75 lbs., phosphoric acid 48 lbs., and nitrogen in "$\frac{1}{3}$ ration" 24 lbs., in "$\frac{2}{3}$ ration" 48 lbs., and "full ration" 72 lbs. per acre.

C. 1879, 1880, and 1881. W. I. BARTHOLEMEW, Putnam, Conn. *Soil.*—Hill land, dark loam, compact subsoil, worn-out meadow. Experiment repeated with the same fertilizers and crops on the same plots year after year. *Weather.*—1879, cold, wet, unfavorable; 1880, favorable; 1881, very unfavorable.

I. CHARLES FAIRCHILD, Middletown, Conn. *Soil.*—Upland, sandy loam, sandy subsoil, rather dry. *Previous crop.*—Corn. *Weather.*—Favorable.

(Concerning further details as to soil, culture, weather, etc., see page ——.)

No. of plot.	FERTILIZERS. Classification.	Kinds and amounts per acre.	Nitrogen.	POTATOES—YIELD PER ACRE IN BUSHELS. C. '79. Good.	C. '79. Poor.	C. '79. Total.	C. '80. Good.	C. '80. Poor.	C. '80. Total.	C. '81. Good.	C. '81. Poor.	C. '81. Total.	I. '81. Total.	Total average.	OATS—(STRAW IN POUNDS). Grain.	Straw.
				Bu.	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Lbs.*
0		0. No manure		30	16	46	50	28	78	16	28	44	28	49	26.9	1,180
1	GROUP I.	1. Nitrogen mixture (1)	$\frac{1}{3}$ ration	22	20	42	80	10	90	26	22	48	42	55	38.1	1,820
2	GROUP I.	2. Superphosphate, 300 lbs. (2)		46	32	78	80	32	112	34	24	58	56	76	33.8	1,800
3	GROUP I.	3. Muriate of potash, 150 lbs. (3)		24	22	46	100	16	116	24	26	50	60	68	31.3	1,720
4	GROUP II. Valuable ingredients, two by two.	4. Nitrate of soda, 150 lbs.; Superphosphate, 300 lbs	$\frac{1}{3}$ ration	78	36	114	90	22	112	32	26	58	94.7	94.7	51.9	2,660
5	GROUP II. Valuable ingredients, two by two.	5. Nitrate of soda, 150 lbs.; Mur. of potash, 150 lbs.	$\frac{1}{3}$ ration	32	20	52	86	26	112	26	26	52	68	71	42.5	2,160
6	GROUP II. Valuable ingredients, two by two.	6. Superphos., 300 lbs.; Mur. pot., 150 lbs. (Mixed min'l fertilizers (4))		81	34	115	82	32	114	54	20	74	90.7	98.4	33.8	2,280
7	GROUP III. Nitrogen (as nitrate of soda) in different proportions.	7. Mixed min. fertilizers (as No. 6); Nitrate of soda, 150 lbs.	$\frac{1}{3}$ ration	84	46	130	124	28	152	76	24	100	124.7	126.7	54.4	3,500
8	GROUP III. Nitrogen (as nitrate of soda) in different proportions.	8. Mixed mineral fertilizers; Nitrate of soda, 300 lbs.	$\frac{2}{3}$ ration	108	40	148	166	36	202	66	30	96	138.7	146.2	59.4	3,860
9	GROUP III. Nitrogen (as nitrate of soda) in different proportions.	9. Mixed mineral fertilizers; Nitrate of soda, 450 lbs.	Full ration	88	42	130	116	28	144	64	26	90	120	121	59.4	4,380
6a		6a. Mixed min. fertilizers (as No. 6)											94	(94)	36.3	1,760

00		00. No manure	....	32	24	56	62	....	62	28	32	60	46.7	56.2	27.5	1,280
10	GROUP IV.	10. Mixed mineral fertilizers Nitrogen mixture,[2] 150 lbs	$\frac{1}{3}$ ration	134	32	166	100	16	116	84	30	114	122.7	129.7	51.9	3,140
11	Nitrogen in mixture in different proportions.	11. Mixed mineral fertilizers Nitrogen mixture, 300 lbs	$\frac{2}{3}$ ration	106	36	142	122	20	142	82	26	108	144.7	134.2	55.6	3,380
12		12. Mixed mineral fertilizers Nitrogen mixture, 450 lbs	Full ration	116	30	146	108	30	138	92	22	114	144.7	135.7	59.4	3,780
6*b*		6*b*. Mixed min. fertilizers (as No. 6)	....	......	....	......	......	....	......	......	......	......	110	(110)	33.8	1,760
13	GROUP V.	13. Mixed mineral fertilizers Sulphate of ammonia, 225 lbs	$\frac{2}{3}$ ration	112	44	156	114	26	140	78	24	102	135.3	133.3	61.9	3,700
14	Nitrogen, $\frac{2}{3}$ ration, in different combinations.	14. Mixed mineral fertilizers Dried blood, 450 lbs	$\frac{2}{3}$ ration	110	48	158	132	26	158	86	24	110	134.7	140.2	53.8	3,080
15		15. Peru. guano, "Standard," 550 lbs Muriate of potash, 150 lbs	$\frac{2}{3}$ ration	92	40	132	126	28	154	76	26	102	133.3	130.3	54.4	2,980
16		16. Mixed min. fertilizers (as No. 6)	....	86	38	124	126	32	158	62	28	90	96	117	35.0	1,760
000		000. No manure	....	......	....	......	......	....	......	......	......	......	29.3	(29.3)	26.3	1,120

TABLE III.—SPECIAL NITROGEN EXPERIMENTS.

Effects of nitrogenous fertilizers upon corn, cotton, clover, and potatoes.

Potash supplied at rate of about 75 lbs. per acre; phosphoric acid, 48 lbs.; and nitrogen in "⅓ ration" 24 lbs., in "⅔ ration" 48 lbs., and "full ration" 72 lbs. per acre.

L. 1881. W. C. NEWTON, Durham, Conn. *Soil.*—Old meadow, hill land, dark loam, moist subsoil. *Weather.*—Unfavorable.
M. 1881. Prof. C. L. INGERSOLL, Purdue University, Lafayette, Ind. *Soil.*—Upland, level, black, similar to prairie; gravel subsoil. *Weather.*—Very dry and unfavorable.
N. 1881. C. E. THORNE, Ohio State University, Columbus, Ohio. *Soil.*—Clayey loam, subsoil similar to surface soil, retentive. *Weather.*—Very dry.
O. 1881. J. W. PIERCE, West Milbury, Mass. *Soil.*—Worn-out grass land. clay loam, gravelly subsoil. *Weather.*—Cold and unfavorable.
P. 1881. EDWARD HICKS, Old Westbury, N. Y. *Soil.*—Level, sandy loam, yellow loam subsoil. *Weather.*—Dry and unfavorable.
Q. 1881. Prof. SAMUEL JOHNSON, Michigan Agricultural College, Lansing, Mich. *Soil.*—Level, upland, sandy loam; gravelly subsoil. *Weather.*—Dry, cold, and unfavorable.
R. 1881. Prof. W. C. STUBBS, Alabama Agricultural and Mechanical College, Auburn, Ala. *Soil.*—Worn-out pasture, sandy, light, well drained, reddish yellow clay, subsoil. *Weather.*—Dry and unfavorable.
S. 1881. J. M. MANNING, Taunton, Mass. *Soil.*—Upland, sandy loam. loose; yellow sand subsoil. *Weather.*—Unfavorable.
(Concerning further details as to soil, culture, weather, &c., see page —.)

No. of plot.	FERTILIZERS.			YIELD PER ACRE.																
				CORN.														COTTON.	CLOVER.	POTATOES
				M. '81.		N. '81.		O. '81.		P. '81.			Q. '81.			L. '81.		R. '81.	S. '81.	M. '81.
	Classification.	Kinds and amounts per acre.	Nitrogen.	Total.	Stalks.	Total.	Stalks.	Total.	Stalks.	Good.	Poor.	Total.	Good.	Poor.	Total.	Total.	Total average corn.	Total.	Total.	Total.
				Bu.	Lbs.	Bu.	Lbs.	Bu.	Lbs.	Bu.	Bu.	Bu.	Bu.	Bu.	Bu.	Bu.	Bu.	Lbs.	Lbs.	Bu.
0		0. Nothing	....	38.2	1,760	40.0	2,040	10.3	860	13.0	3.3	16.3	37.4	7.3	44.7	12.52	27.0	587	480	12.8
1	PRELIMINARY GROUP.	1. Nitrate of soda	⅓ ration	35.9	1,920	44.3	2,420	11.7	1,080	23.2	2.8	26.0	45.6	7.5	53.1	22.5	32.2	865	700	42.7
2		2. Superphosphate	....	36.4	1,920	48.6	2,480	16.0	1.360	18.8	4.0	22.8	41.8	6.3	51 2	13.8	31.4	1,162	1,200	17.1
3		3. Muriate of potash	....	34.5	1,840	48.6	2,600	17.7	1,640	30.0	4.5	34.5	47,0	5.1	52.0	15.0	33.7	564	940	9.1

4	Valuable ingredients, singly and two by two.	4. Nitrate of soda. Superphospate	$\frac{1}{3}$ ration...	33. 6	1, 760	50. 3	2, 720	14. 3	1, 140	20. 2	4. 3	24. 3	54. 8	6. 9	61. 6	23. 8	34. 6	1, 599	1, 080	10. 7
5		5. Nitrate of soda. Muriate of potash	....	34. 5	1, 840	44. 9	2, 200	23. 0	1, 960	24. 2	5. 3	29. 5	39. 6	4. 0	43. 6	23. 8	33. 2	932	560	5. 9
6		6. Superphosphate. Muriate potash.. } Mixed minerals	....	34. 5	1, 888	52. 0	2, 860	34. 6	2, 220	25. 4	2. 8	28. 2	55. 1	3. 8	59. 0	13. 8	37. 0	1, 219	1, 140	13. 9
7	Nitric Acid Group.	7. Mixed minerals, as No. 6... Nitrate of soda	$\frac{1}{3}$ ration...	37. 3	1, 840	49. 1	2, 920	34. 0	2, 200	23. 2	5. 5	28. 7	52. 9	5. 9	58. 8	23. 3	38. 5	1, 541	1, 200	38. 6
8		8. Mixed minerals. Nitrate of soda	$\frac{2}{3}$ ration...	32. 5	1, 760	45. 7	2, 440	35. 7	2, 440	29. 8	4. 0	33. 8	51. 3	4. 3	55. 6	41. 7	40. 8	1, 404	1, 460	79. 4
9		9. Mixed minerals. Nitrate of soda	Full ration.	33. 1	1, 920	47. 4	3, 080	41. 4	2, 660	27. 0	4. 5	31. 5	44. 1	5. 0	49. 1	56. 7	43. 2	1, 242	1, 480	85. 9
6*a*		6*a*. Mixed minerals, as No. 6.....	....	33. 4	2, 000	46. 0	2, 760	37. 7	2, 400	24. 8	5. 2	30. 0	52. 3	4. 4	56 7	16. 3	36. 7	3, 115	1, 660	124. 3
10	Ammonia Group.	10. Mixed minerals. Sulph ammonia	$\frac{1}{3}$ ration...	36. 1	2, 080	41. 7	2, 640	39. 4	2, 720	23. 0	4. 8	27. 8	52. 0	8. 8	55. 7	28. 5	38. 2	1, 116	1, 880	130. 7
11		11. Mixed minerals. Sulph. ammonia	$\frac{2}{3}$ ration...	38. 4	2, 160	42. 3	2, 700	40. 3	2, 720	26. 6	4. 2	30. 8	55. 0	3. 9	58. 9	42. 5	42. 2	1, 265	2, 000	127. 4
12		12. Mixed minerals. Sulph. ammonia	Full ration.	34. 0	2, 160	43. 4	2, 600	39. 4	2, 440	27. 0	5. 5	32. 5	46. 4	4. 0	50. 4	48. 3	41. 3	1, 162	2, 400	89. 6
6*b*		6*b*. Mixed minerals............	....	35. 7	2, 240	48. 3	2, 740	28. 6	1, 980	24. 0	5. 0	29. 0	45. 9	5. 2	51. 0	.....	....	....	1, 440	55. 4
13	Organic Nitrogen Group.	13. Mixed minerals. Dried blood	$\frac{1}{3}$ ration...	34. 0	2, 080	41. 1	2, 360	35. 4	2, 200	33. 0	4. 6	37. 6	44. 2	5. 2	49. 4	28. 8	37. 7	1, 357	1, 620	37. 3
14		14. Mixed minerals. Dried blood	$\frac{2}{3}$ ration...	34. 5	2, 160	41. 4	2, 580	37. 0	2, 120	32. 7	3. 6	36. 3	47. 6	4. 0	51. 6	33. 8	40. 8	1, 300	1, 940	41. 6
15		15. Mixed minerals. Dried blood	Full ration.	33. 4	2, 320	39. 4	2, 420	39. 0	2, 480	32. 0	3. 2	35. 2	58. 2	3. 2	61. 4	40. 6	41. 5	1, 127	2, 420	38. 4
6*c*		6*c*. Mixed minerals, as No. 6.....	....	33. 4	2, 240	40. 9	2, 720	....	.....	37. 2	2. 5	39. 7	51. 9	5. 3	57. 1	20. 6	31. 9	....	1, 200	40. 5
00		00. No manure..................	....	31. 0	1, 685	35. 4	2, 320	....	....	13. 5	3. 0	16. 5	25. 6	6. 1	31. 7	13. 8	21. 4	449	800	11. 7

TABLE IV.—GENERAL EXPERIMENTS WITH CORN, 1878.

Yields of shelled corn per acre with different fertilizers.

Number of experiment.	0		I.		II.		III.		IV.		XIII.		V.		VI.		VII.				00	
	No manure.		Nitrate of soda, 200 pounds.		Dissolved bone-black, 300 pounds.		Muriate of potash, 200 pounds.		Nitrate of soda, 150 pounds; dissolved bone-black, 300 pounds.		Nitrate of soda, 150 pounds; muriate of potash, 200 pounds.		Dissolved bone-black, 300 pounds; muriate of potash, 200 pounds.		Nitrate of soda, 150 pounds; dissolved bone-black, 300 pounds; muriate of potash, 200 pounds.		Plaster, 200 pounds.		Farm manure.		No manure.	
	Cost per acre.		$7.50		$5.25		$4.50		$10.88		$10.13		$9.75		$15.38		$0.80		Variable.			
	Corn.	Stalks.	Corn.	Stalks.	Corn.	Stalks.	Corn.	Stalks.	Corn.	Stalks.	Corn.	Stalks.	Corn.	Stalks.	Corn.	Stalks.	Corn.	Stalks.	Corn	Stalks.	Corn.	Stalks.
	Bush.	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*	*Bush.*	*Lbs.*
1	[ ]		6.9		6.5		6.5		8.2		8.7		8.2		10.0		5.0					
2	7.0	2,250	17.5	3,600	10.3	2,800	9.2	2,400	16.5	3,550	15.0	4,050	18.6	3,840	13.5	2,900	14.4	3,000	48.6	5,500		
3	6.4		3.2		23.0		5.8		25.6				22.2		27.4		10.6		10.4		6.6	
4	11.0	1,248	18.0	1,408	11.0	1,184	42.0	3,072	16.0	1,344			48.0	3,744	56.0	2,849	9.0	1,050	50.0	2,944	8.0	1,050
5	5.5	190	7.5	121	10.7	154	7.8	116	18.4	225			14.5	212	18.5	225	9.4	138				
6			6.2		20.0		12.5		32.5				25.0		30.0		17.5				7.5	
7	10.0	520	9.0	570	17.5	790	7.5	610	22.5	990			16.3	830	20.0	1,310	7.0	350	20.0	770	7.5	430
8	7.5		5.6		20.7		7.6		28.8				23.8		27.5		7.5		32.5			
9	5.0		11.0		8.5		19.5		17.0		28.0		26.0		31.0		15.0		23.5			
10	27.5		35.0		35.0		32.5		35.0		32.5		35.0		32.5		27.5		40.0		31.9	1,680
11	28.7	1,610	35.6	1,950	37.5	2,000	35.6	2.300	38.7	2,170			41.9	2,340	51.2	2,870	32.5	1,280	32.5			
12	26.3		35.1		49.5		35.1		67.4				67.4		86.1		55.6		48.1		26.3	
13	27.5	1,550	51.9	2,300	40.0	2,000	49.1	2,200	47.1	2,350	52.4	2,500	47.4	2,220	53.7	2,450	40.0	1,800	52.6	2,340		
14	20.2		40.5		57.2		30.0		67.9				71.0		70.5		23.0		60.0			
15	20.5		43.7		43.7		39.9		46.3		26.0		33.4		41.1		33.0		29.6			
16	24.0		18.5		30.5		20.5		32.0				32.0		31.0		26.0		36.5			
17	35.2		41.0		34.0		45.2		42.3				44.1		51.0		32.0		39.5		32.0	
18	30.5		37.2		36.6		35.0		39.3				42.7		42.7		31.0		47.5			
19	33.0		32.0		31.0		39.3		34.4		30.0		39.6		40.0		27.0		45.0			
20	32.8	2,700	41.8	3,600	32.8	3,600	45.3	4,050	48.5	4.500			64.8	5,850	72.3	8,550	39.0					
21	48.7		58.3		62.6		70.2		68.5		49.9		59.2		70.3		42.6		45.2		41.5	

22	47.0	....	58.0	....	56.0	....	58.4	....	63.3	....	......	....	63.0	....	64.0	....	53.0	....	65.0	....	52.5	....
23	64.9	....	63.5	....	64.7	....	64.3	....	65.9	....	69.1	....	69.3	....	80.6	....	65.7	....	76.7	....	......	....
24	49.2	....	60.0	....	54.0	....	37.8	-- ----	54.3	....	......	-- ----	57.3	....	76.0	....	48.3	....	66.8	....	41.3	..... --
Average(1)	24.6	....	30.4	....	33.5	....	33.3	....	39.1	....	39.6	....	42.9	....	48.6	....	28.9	....	45.9	....	24.4	....

(1) Including also experiments A, B, and C of Table I.

Kinds and amount of farm manures. *Experiment* 3, hen manure; 4, yard manure, 9 cords per acre; 7, manure, 20 loads; 8, stable manure, 6½ cords; 9, manure, 600 bushels; 10, manure, 16 loads; 11, hen manure, 15 bushels; 12, yard manure, 26 loads; 13, yard manure, 30 loads; 14, yard manure, 18 cords; 15, manure, 20 loads; 16, hen manure, ½ handfull in each hill; 17, yard manure, 10 loads; 18, hog manure, 7½ cords; 19, yard manure; 21, stable manure, 8 cords; 22, yard manure, 40 loads; 23, stable manure, 9 cords.

Yields with other fertilizers, experiment 8.—Ashes, 40 bushels, 5.6; 9, ashes, 25 bushels, 35.0; 11, lime, 31.9; 12, leached ashes, 100 bushels, 46; 17, lime, 30 bushels, 34; 20, unleached ashes, 40 bushels, 44.

Number.	Experimenters.	Surface soil. Kind.	Surface soil. Texture.	Surface soil. Moisture.	Subsoil.	Previous cropping.	Weather.			Fertilizers, how applied.
1	Emmor K. Haight, Freehold, N. J	Clay	Compact	Medium	Compact	Hay	Warm	Moist	Favorable	Broadcast.
2	Buel Lavdon, South Hero, Vt	Clay loam	Loose	do	do	Oats	do	Wet	do	Do.
3	G. Gilbert Childs, Swopes Depot, Va	do	Compact	Dry	Red clay	Pasture	do	do	do	Do.
4	J. H. Stiles, Morris Plains, N. J	Gravel	Loose	Medium	Loose	Corn	Cool	do	do	Do.
5	J. J. Dearing, Covington, Ga	Red Clay	do	do	Sandy	Pasture		do	do	Drilled.
6	David B. Wertz, Johnstown, Pa	Yellow clay	do	Dry	Clay	Rye	Cool	do	Unfavorable	
7	W. C. Holman, Graham, N. C	Sandy loam	do	do	Red clay	Corn	do	Dry	Favorable	Hill.
8	Nathan B. Lewis, Pine Hill, R. I	Gravel	Light	do	Gravel	Rye	do	Moist	do	Broadcast.
9	Z. E. Jameson, Irasburgh, Vt	Sandy	do	Medium	Loose	Hay	Warm	do	do	Do.
10	Ed. F. Smith, Tunbridge, Vt	Loam	Compact	Wet	Clay	Corn	do	Dry	do	Do.
11	L. W. Stone & Son, Waverly, Pa	Clay loam	Loose	Dry	Compact	Hay	do	Moist	do	Do.
12	Halsey P. Clarke, Wyoming, R. I	Loam			Gravel	do				Do.
13	Seth H. Rising, West Rupert, Vt	Gravel	Loose	Dry	do	Corn	Cool	Moist	Unfavorable	Do.
14	C. Miller & Son, Pomfert, Vt	Loam	Light	Medium	Sand and clay	Hay	do	do	Favorable	Do.
15	Charles P. Gale, Plainfield, Vt	Sandy loam	do	Dry	Yellow loam	do	Warm	Dry	do	Do.
16	Jonathan Dunham, Etna, N. Y	Gravelly loam	Loose	do	Stony clay	do	do	Moist	do	Hill.
17	A. B. Clarke, Milton, N. Y	Loam	do	do	Compact	do	do	do	do	Broadcast.
18	M. W. Ladd, Woodstock, Vt	Sandy loam	do	do	Loose	do	do	do	do	Do.
19	H. Bradley, Brattleboro', Vt	do	Light	do	Sandy	Pasture				Do.
20	William F. Segar, Wyoming, Vt.	do	Loose	Medium	Clay	Hay	Warm	Moist	Favorable	Do.
21	James K. Toby, Calais, Vt	Loam	do	Dry	Loam	Potatoes	Cool	Dry	do	Do.
22	Cicero Blake, Kent, Ohio	Clay loam	Light	do	Clay	Hay	Warm	do	Unfavorable	Do.
23	Ora Paul, Woodstock, Vt	Loam	do	do	do	do	do	Moist	Favorable	Do.
24	Edward Hicks, Old Westby, N. Y	Sandy loam	Loose	do	Gravelly loam	Foddercorn	do	do	do	Hill.

TABLE V.—GENERAL EXPERIMENTS WITH POTATOES, TURNIPS, AND OTHER CROPS IN 1878.

Yields per acre with different fertilizers.

Number of experiment.	Number of fertilizer.	0.	A.	B.	C.	D.	E.	F.	G.	H.		00.
	Fertilizers per acre.	No manure.	Nitrate of soda, 200 lbs.	Dissolved bone-black, 300 lbs.	Muriate of potash, 200 lbs.	Nitrate of soda, 150 lbs.; dissolved bone-black, 300 lbs.	Nitrate of soda, 150 lbs.; muriate of potash, 200 lbs.	Dissolved bone-black, 300 lbs.; muriate of potash, 200 lbs.	Nitrate of soda, 150 lbs.; dissolved bone-black, 300 lbs.; muriate of potash, 200 lbs.	Plaster, 200 lbs.	Farm manures.	No manure.
	Cost per acre	....	$7.50	$5.25	$4.50	$10.88	$10.13	$9.75	$15.38	$0.80	Variable.	
25	Potatoes	134.0	127.0	127.0	136.0	154.0	122.0	115.0	138.0	132.0	129.0	141.0
26		31.2	30.8	28.4	69.0	37.2	....	76.4	75.6	31.6	74.8	......
27		130.0	162.0	200.0	125.0	210.0	....	220.0	250.0	150.0	....	......
28		120.0	102.0	105.0	140.0	150.0	....	162.0	185.0	100.0	115.0	90.0
29	bu. per acre	60.0	76.6	100.0	93.3	106.6	....	150.0	170.0	93.3	146.0	60.0
30		133.0	13.9	138.0	160.0	149.0	137.0	165.6	200.0	....	....	......
31		141.0	133.0	165.0	209.0	206.0	....	247.5	270.4	158.0	215.4	......
32		121.0	117.0	168.0	214.0	176.0	....	145.0	167.0	123.0	170.0	......
33		30.0	40.0	80.0	20.0	100.0	60.0	100.0	140.0	60.0	80.0	35.0
	Average	100.0	103.0	123.4	129.6	143.2	106.0	153.4	177.3	106.0	132.9	81.5
34	Sweet potatoes	68.0	91.0	77.0	110.0	93.0	....	166.0	177.0	60.0	....	......
35		....	120.0	130.0	140.0	120.0	....	140.0	170.0	....	....	......
36	bu. per acre	26.5	159.0	79.0	189.0	92.5	....	92.5	212.0	....	....	53.0
37		73.0	141.0	73.0	194.0	145.0	194.0	218.0	290.0	....	290.0	73.0
38	Turnips do	225.0	285.0	315.0	240.0	428.0	203.0	413.0	518.0	263.0	300.0	......
39		516.0	565.0	615.0	583.0	593.0	661.0	656.0	785.0	673.0	580.0	505.0
40	Sugar beets do	787.3	1,013.3	1,174.0	851.3	1,116.0	988.3	1,090.6	1,118.6	960.6	....	803.3
41	Cotton lbs. per acre	104.5	38.5	242.0	66.0	599.5	....	457.0	693.0	44.0	....	......
42	Cow peas bu. per acre	3,0	4.0	5.0	6.0	6.0	....	8.0	10.0	4.0	....	......

Kinds and amounts of farm manure.—Experiment 25, stable manure, 8 cords; 28, yard manure, 30 loads; 29, stable manure, 6½ cords; 31, stable manure, 35 loads; 32, stable manure, 20 loads; 39, stable manure, 8 cords.

Yields with other fertilizers.—Experiment 29, lime, 500 pounds = 63.3; 36, ashes, 40 bushels = 212.

Number.	Experimenters.	Surface soil.			Subsoil.	Previous cropping.	Weather.			Fertilizers, how applied.
		Kind.	Texture.	Moisture.						
25	James K. Toby, Calais, Vt	Loam	Loose							
26	T. H. Stiles, Morris Plains, N. J	Clay loam	do	Medium	Hard-pan		Cool	Wet	Favorable	Broadcast.
27	W. S. Bartholomew, Putnam, Conn	Loam	Compact	do	Compact	Corn and beans			do	
28	R. P. Wolcott, Holland Patent, N. Y.	do	Light	Dry	Clay loam	Fodder corn	Warm	Moist	do	Broadcast.
29	S. W. Crocker, Saint Albans, Me	Clayey	do	Medium	Hard-pan	Grass	Cool	Wet	Unfavorable	Hill.
30	J. R. Kinerson, Peacham, Vt	Sandy loam	Loose	Dry	Sandy	Hay	Warm	Moist	Favorable	Broadcast.
31	Moody P. Marshall, Lancaster, N. H	Stony land	Light	Medium		Oats	Cool	do	do	Drill.
32	Moody P. Marshall, Lancaster, N. H	do	do	do	Sandy	do	do	do	do	Do.
33	Hiram A. Cutting, Lunenburgh, Vt	Loam	do	Dry	Hard gravel	Hay	do	Wet	Unfavorable	
34	A. P. Arnold, Vineland, N. J	Sandy loam	Loose	do	Sandy	Corn	do	do	do	Drill.
35	A. P. Arnold, Vineland, N. J	do	do	do	do	do	do	do	do	Do.
36	M. Chesboro, Mandarin, Fla	Fine sand	Compact	Medium	Yellow sand	Sweet potatoes				
37	Charles Parry, Cinnaminson, N. J	Sandy	Light	Dry	Sand and gravel	Asparagus	Warm	Moist	Favorable	Row.
38	Prof. J. Farrington, Orono, Me	Heavy clay	Compact	Medium		Meadow				Broadcast.
39	James K. Toby, Calais, Vt	Loam	Loose	Dry	Compact	Potatoes	Cool	Dry	Favorable	Do.
40	Henry Lane, Cornwall, Vt	Clay loam			Slate-rock	Onions				Do.
41	J. J. Dearing, Covington, Ga	Red clay	Compact	Dry	Red clay	Fallow	Warm	Moist	Favorable	Drill.
42	Willard R Hall, Albion, Fla	Sandy	Light	do	Yellow sand		do	do	do	Do.

TABLE VI.—GENERAL EXPERIMENTS WITH CORN, 1879.

Yields per acre with different fertilizers.

Number of experiment.	0.		A.		B.		C.		D.		E.		F.		G.		H.				OO.	
	No manure.		Nitrate of soda, 200 lbs.*		Dissolved bone-black, 300 lbs.		Muriate of potash, 200 lbs.†		Nitrate of soda, 150 lbs.; dissolved bone-black, 300 lbs.		Nitrate of soda, 150 lbs.; muriate of potash, 200 lbs.†		Dissolved bone-black, 300 lbs.; muriate of potash, 200 lbs.		Nitrate of soda, 150 lbs.; dissolved bone-black, 300 lbs.; muriate of potash, 200 lbs.‡		Plaster, 200 lbs.		Farm manures.		No manure.	
Cost per acre.			$7.50.		$5.25.		$4.50.		$10.88.		$10.13.		$9.75.		$15.38.		$0.80.		Variable.			
	Corn.	Stalks.	Corn.	Stalks.	Corn.	Stalks.	Corn.	Stalks.	Corn.	Stalks	Corn.	Stalks.	Corn.	Stalks.	Corn.	Stalks.	Corn.	Stalks.	Corn.	Stalks.	Corn.	Stalks.
	Bu.	*Lbs.*	*Bu.*	*Lbs.*	*Bu.*	*Lbs.*	*Bu.*	*Lbs.*	*Bu.*	*Lbs.*	*Bu.*	*Lbs.*	*Bu.*	*Lbs.*	*Bu*	*Lbs.*	*Bu.*	*Lbs.*	*Bu.*	*Lbs.*	*Bu.*	*Lbs.*
1	18.5	...	20.3	...	20.3	...	17.3	...	19.2	...	12.9	...	17.6	...	20.1	...	13.0	...	...	...	...	...
C	7.7	...	7.4	...	36.5	...	7.7	...	41.4	...	7.1	...	42.0	...	45.7	...	...	...	36.0	...	8.5	...
3	3.3	730	2.7	1,000	12.0	1,880	6.7	1,980	12.0	2,760	5.5	1,620	16.7	3,200	13.7	3,300	3.5	920	39.7	...		...
4	19.7	1,800	24.2	1,600	22.3	1,800	11.0	1,200	31.3	1,650	14.0	1,500	27.2	2,250	33.4	2,250	25.8	2,250	18.0	2,100	...	...
5	[31.7]	2,360	37.6	2,360	14.6	2,260	6.9	1,880	29.8	3,660	18.4	2,300	10.1	2,460	18.8	2,740	3.7	1,460	...	...	...	...
6	8.0	1,690	14.7	2,110	23.3	2,890	29.4	3,410	38.7	4,000	38.2	3,800	46.2	4,120	80.2	4,450	10.6	2,200	90.5	4,500	...	...
7	5.7	...	6.8	...	16.6	...	10.4	...	17.7	...	10.5	...	21.7	...	26.6	...	19.2	...	32.5	...	11.6	...
8	11.3	1,215	11.2	1,276	16.6	1,316	11.0	1,519	18.9	1,413	10.0	1,137	13.3	1,519	15.9	1,661	4.5	1,013	23.9	1,620	...	...
9	12.5	...	37.5	...	41.2	...	25.0	...	22.5	...	38.0	...	45.0	...	45.0	...	37.4	...	...	...	...	...
F	8.3	...	6.8	...	7.0	..	41.3	...	20.5	...	39.3	...	50.3	...	40.7	...	...	...	46.5	...	7.1	...
11	23.9	2,200	16.0	4,000	26.2	3,200	11.0	3,250	44.2	3,200	14.3	3,500	21.4	3,600	37.5	4,360	19.0	1,700	14.8	1,680	...	...
12	20.3	...	22.3	...	20.0	...	24.6	...	37.0	...	44.3	...	24.6	...	19.4	...	14.0	...	...	...	8.3	...
13	21.9	...	27.5	...	33.7	..	23.7	...	30.0	...	28.7	...	31.2	...	38.7	...	34.7	...	15.0	...	...	...
14	22.7	1,760	13.3	2,560	49.4	2,880	45.7	3,200	54.5	3,360	42.1	3,360	56.1	3,680	65.0	5,600	...	...	58.5	5,120	...	...
15	25.4	1,440	22.0	1,680	28.6	1,730	37.1	2,240	32.3	2,200	47.1	3,360	33.4	2,640	57.5	4,480	38.0	2,880	55.5	3,920	...	...
16	32.5	...	47.5	...	40.0	...	55.0	...	50.0	...	41.2	...	42.5	...	41.2	...	30.0	...	42.5	...	32.5	...
17	38.0	5,920	44.0	6,560	80.0	9,120	73.0	7,420	70.0	7,840	50.0	8,640	64.0	8,000	64.0	8,480	44.0	6,560	...	...	44.0	7,120
18	34.0	...	24.3	...	45.7	...	31.6	...	45.6	...	24.4	...	48.8	...	35.7	...	46.2	...	...	...	...	...
19	30.0	...	35.7	...	34.7	...	27.5	...	28.3	...	28.2	...	29.0	...	28.2	...	23.3	...	...	...	21.2	...
20	33.3	...	31.0	...	67.5	...	34.5	...			...	..		...	61.5	...	71.8	...	...	...	...	...
21	36.8	1,995	60.9	2,820	48.6	3,261	63.5	3,540	62.8	3,210	51.9	2,700	60.4	2,940	63.7	3,240	...	...	69.0	3,600	...	...
22	32.5	...	53.3	3,680	54.5	3,660	59.6	4,660	69.6	5,000	82.2	6,000	76.5	5,640	82.7	5,620	58.7	4,240	55.3	...	43.1	...
23	53.5	...	52.0	...	61.0	...	54.5	...	47.5	...	48.5	...	68.5	...	75.5	...	64.0	...	...	...	40.0	...
E	42.0	...	49.2	...	46.0	...	59.0	...	41.1	...	58.0	...	63.4	...	60.8	...	...	..	...	...	44.3	...
25	40.9	3,700	59.6	4,240	42.2	41.40	41.1	4,700	57.0	4,340	60.0	5,880	37.0	5,640	60.0	5,540	37.5	4,240	51.4	...	42.5	4,140
26	44.0	...	60.0	...	73.8	...	56.2	...	65.0	...	57.5	.	61.2	...	81.2	...	45.0	...	...	...	...	...
Average	24.0	...	30.3	...	36.9	...	33.2	...	38.6	...	34.7	...	40.1	...	46.7	...	29.1	...	43.2	...	27.5	...

Number.	Experimenters.	Surface soil.			Subsoil.	Previous cropping.	Weather.			Fertilizers, how applied.
		Kind.	Texture.	Moisture.						
1	John Flannagan, Kans	Clay		Dry	Clay	Corn	Warm	Dry	Unfavorable	Broadcast.
C	W. I. Bartholomew, Conn	Clay loam	Loose	Medium	Compact	Meadow	Cold	Wet	do	Hill.
3	John W. Pierce, Mass	do	Compact	Dry	Gravelly hardpan	do	do	do	do	Hill and broadcast.
4	Buel Landon, Vt	Clay calc	do	do	Clay	do	do	Dry	Very unfav	Broadcast.
5	A. P. Arnold, N. J	Sandy loam	Loose	do	Gravelly clay	Vineyard			Favorable	Do.
6	W. C. Atwood, Conn	do	do	Medium	Gravelly loam	Rye			do	Drill.
7	George Spalding, N. H	Loam	do	do	Loam	Meadow	Cool		Unfavorable	Broadcast.
8	J. M. Manning, Mass	Sandy loam	do	do	Sand	do	Variable	Variable	Favorable	Do.
9	Frank Bourne, Mass	Gravelly loam	do	Dry	Gravelly and stony	Pasture			do	Do.
F	J. B. Mead, Vt	Clay loam	Light	do	Compact	Oats	Cold		Very unfav	Do.
11	Zeno Benson, Mass	Loam	do	do	Loam	Pasture	Medium	Medium	do	Do.
12	W. S. Simmons, Mass	Sandy loam	Loose	Medium	Sand	Rye	Variable	Variable	Favorable	Drill.
13	C. Miller & Son, Vt	do	Light	Dry		Meadow		Dry	Unfavorable	Broadcast.
14	J. M. Manning, Mass	do	do	Medium	Sand	Fallow	Variable	Vari ble	Favorable	Do.
15	J. A. Chedel, Vt	do	do	do	Sandy loam	Meadow	do	do	do	Do.
16	E. N. Bissell, Vt	Clay loam	Compact	Wet	Clay	do	Dry		Unfavorable	Do.
17	J. L. Dow, N. H	Loam	Light lse.	Dry	Hardpan	Corn	Cold		do	Hill.
18	W. Eliason, Md	Gravelly loam	Compact	do	Clay	Grain			do	Do.
19	H. Pitts, D. C	Sandy loam	Light	do	do	Pasture	Hot	Dry	Very unfav	Broadcast.
20	H. T. Stevens, N. Y	Gravelly loam	Loose	do	Clay stony	Clover		do	do	Do.
21	H. M. Swift, N. Y	do	do	do	Loose	Meadow	Warm		do	Hill.
22	Edward Hicks, N. Y	Sandy loam	Light	do	Loam	do			Favorable	Broadcast.
23	H. C. Loose, Md	Calcareous	Loose	do	Clay				do	Do.
E	Chester Sage, Conn	Gravelly loam	Compact	do	Loam	Meadow			do	Do.
25	James D. Winslow, Vt	Sandy	Light	do	Sand	do	Variable	Variable	do	Do.
26	W. H. Philbrook, N. H	Gravelly	do	do	Gravelly	do			do	

* In experiments C, F, and E, 150 lbs., costing \$5.62½. † In same experiments, 150 lbs., costing \$3.37½.

‡ *Kinds and amounts of farm manure per acre.*—Experiment C, "hog manure, 20 cart loads"; 3, "stable manure, 7 cords"; 6, "yard manure, 15 cords"; 7, "stable manure, 4 cords"; 8, "stable manure and hog manure, 7½ cords;" 11, "hen manure, 240 pounds"; 13, "yard manure, 15 cords"; 14, "stable manure and hog manure, 9 cords;" 15, "yard manure 7½ cords"; 16, "stable manure, 20 loads"; 22, "stable manure, 6⅔ loads"; 25, "stable manure, 30 loads."

TABLE VII.—GENERAL EXPERIMENTS WITH POTATOES, TURNIPS, AND OTHER CROPS, 1879.

Yields per acre with different fertilizers.

Number of experiment.	Number of fertilizer.	0.	A.	B.	C.	D.	E.	F.	G.	H.		00.
	Fertilizers per acre.	No manure.	Nitrate of soda, 200 lbs.*	Dissolved bone-black, 300 lbs.	Muriate of potash, 200 lbs.†	Nitrate of soda, 150 lbs; dissolved bone-black, 300 lbs.	Nitrate of soda, 150 lbs; muriate of potash, 200 lbs.	Dissolved bone-black, 300 lbs; muriate of potash, 200 lbs.	Nitrate of soda, 150 lbs; dissolved bone-black, 300 lbs. muriate of potash, 200 lbs.	Plaster, 200 lbs.	Farm manures.	No manures.
	Cost per acre	....	$7.50	$5.25	$4.50	$10.88	$10.13	$9.75	$15.38	$0.80	Variable	
27	Potatoes ... bu.	37	49	38	73	47	59	111	129	35	116	......
C	Potatoes ... bu.	38	32	62	33	96	42	98	109	......	36	44
29	Potatoes ... bu.	46	67	91	46	84	45	79	124	60	53	......
30	Potatoes ... bu.	37	45	136	49	117	44	145	172	41	......	......
31	Potatoes ... bu.	150	180	175	215	220	260	360	370	150	470	......
32	Potatoes ... bu.	......	133	152	140	......	......	......	213	......	182	......
33	Potatoes ... bu.	59	59	67	66	53	56	53	52	63	......	66
34	Potatoes ... bu.	40	56	52	72	54	66	88	98	60	50	......
35	Potatoes ... bu.	29	85	69	38	84	55	76	72	55	76	......
36	Potatoes ... bu.	80	105	110	175	94	125	80	145	90	120	......
37	Potatoes ... bu.	165	75	184	105	180	90	180	225	135	364	150
	Average of 9 experiments in 1879 (4)	50.7	75.3	88.8	85.2	93.2	83.6	121.1	141.2	69.2	131.6	55.0
	Oats:											
38	Grain ... bu.	15.6	15.3	45.6	10.0	58.7	54.4	28.1	40.0	27.8	26.9	......
	Straw ... lbs.	1,640.0	2,046.0	4,400.0	1,100.0	6,440.0	5,860.0	3,380.0	5,760.0	3,120.0	2,720.0	......
39	Grain ... bu.	23.1	31.9	32.5	25.6	45.0	30.0	31.9	43.7	22.5	......	......
40	Cotton ... lbs.	......	......	......	......	1,204.0	819.0	1,035.0	1,023.0	......	......	......
41	Turnips ... do.	......	......	14,520.0	......	9,070.0	......	8,065.0	12,100.0	......	14,520.0	......
42	Beans ... bu.	4.0	3.2	3.8	2.2	4.7	3.9	3.5	5.0	4.5	4.3	......

(*) In experiment C, 150 lbs., costing $5.62½. (†) In same experiment, 150 lbs., costing $3.37½. (‡) *Kinds and amounts of farm manures.*—Experiment 27, stable manure, 10 cords per acre; C, hog manure, 20 cart loads per acre; 31, stable manure, 9 cords per acre; 35, yard manure, 10 tons per acre; 36, stable manure, 30 loads per acre; 37, horse manure and hog manure, 3 cords per acre; 38, yard manure, 10 loads per acre; 41, yard manure; 42, stable manure, 15 cords per acre. (4) Nos. 32 and 37 not included in average.

Number.	Experimenters.	Surface soil.			Subsoil.	Previous cropping.	Weather.			Fertilizers, how applied.
		Kind.	Texture.	Moisture.						
27	Prof. W. H. Jordan, Me	Heavy clay	Compact	Wet	Heavy clay		Cold	Wet	Very unfavorable	Drill.
C	W. I. Bartholomew, Conn	Clay loam	Loose	Medium	Clay	Meadow	do	do	Unfavorable	Hill.
29	Zeno Benson, Mass	Loam	Light	Dry	Loam	Pastnre	Warm	Variable	Favorable	Broadcast.
30	Edward M. Snow, Vt	Dark loom	Loose	do	Loam, compact	Oats	Variable	do	do	Hill.
31	Charles S. Cole, Vt	do	Medinm			do				Broadcast.
32	Henry Arey, Mass	Sandy loom	Light	Dry	Yellow sand	Corn	Warm	Dry	Favorable	Hill.
33	E. G. Reist, Pa	Calcareous	Loose	Medium	Clay	do	Cold	do	Unfavorable	Broadcast.
34	John Labrunn, Mass	Calc. gravelly	Light, loose	Dry	Calc. gravelly	Pasture		Wet	do	Do.
35	P. W. Raidabaugh, Pa	Gravelly	Light	do	Clay		Variable	Dry	Very unfavorable	Drill.
36	Seth H. Rising, Vt	do	Loose	do	Gravelly		do		Unfavorable	Broadcast.
37	A. M. Foster, Vt	Dark loam	Light	do	Compact, stony	Meadow	Cool	Dry		Hill.
38	Dr. H. A. Cutting, Vt	Loam	do	do	Gravel		Cold	Wet	Unfavorable	
39	S. D. Burrows, N. J	Sandy loam	Loose	do	Clay and gravel			Dry	Favorable	Broadcast.
40	J. J. Deering, Ga	"Gray land"	Light	do	Porous	Cotton		Wet	Unfavorable	Drill.
41	H. M. Swift, N. Y	Grav. loam	Coarse	do	Open	Grapes	Warm		Favorable	
42	C. Miller & Son, Vt	Sandy loam	Light	do			do	Dry	do	

TABLE VIII.—GENERAL EXPERIMENTS WITH CORN, 1880.

Yields per acre with different fertilizers.

No. of experiments.	0.		A.		B.		C.		D.		E.		F.		G.		H.				00.	
	No manure		Nitrate of soda, 200 lbs.*		Dissolved bone-black, 300 lbs.		Muriate of potash, 200 lbs.†		Nitrate of soda, 150 lbs.; dissolved bone-black, 300 lbs.		Nitrate of soda, 150 lbs.; muriate of potash, 200 lbs.†		Dissolved bone-black, 300 lbs.; muriate of potash, 200 lbs.†		Nitrate of soda, 150 lbs.; dissolved bone-black, 300 lbs.; muriate of potash, 200 lbs.†		Plaster 200 lbs.		Farm manure.‡		No manure.	
	Cost per acre.		$7 50		$5 25		$4 50		$10 88		$10 13		$9 75		$15 38		$0 80		Variable.			
	Corn.	Stalks.	Corn.	Stalks.	Corn.	Stalks.	Corn.	Stalks.	Corn.	Stalks.	Corn.	Stalks.	Corn.	Stalks.	Corn.	Stalks.	Corn.	Stalks.	Corn.	Stalks.	Corn.	Stalks.
	Bu.	*Lbs.*	*Bu.*	*Lbs.*	*Bu.*	*Lbs.*	*Bu.*	*Lbs.*	*Bu.*	*Lbs.*	*Bu.*	*Lbs.*	*Bu.*	*Lbs.*	*Bu.*	*Lbs.*	*Bu.*	*Lbs.*	*Bu.*	*Lbs.*	*Bu.*	*Lbs.*
1	10.1	......	10.3	......	23.0	......	12.1	......	27.4	......	......	......	23.1	......	31.0	......	......	......	22.9	......	9.7	......
G	11.4	1,220	9.8	2,320	21.1	1,360	14.1	1,000	30.0	4,040	13.0	1,100	20.0	3,220	16.5	3,160	......	......	......	......	7.9	1,300
3	15.7	2,500	18.4	2,320	32.4	2,740	23.0	2,820	13.9	3,160	24.2	2,460	10.0	3,200	20.9	3,400	22.9	3,900	......	......	8.7	2,640
4	16.5	1,488	13.8	1,536	33.8	1,744	22.2	2,176	36.1	3,200	24.8	2,208	35.6	3,184	33.8	3,216	21.0	1,856	26.8	1,904	15.9	1,568
5	22.9	1,160	25.5	1,400	19.2	1,360	29.1	2,000	30.4	1,840	24.5	1,660	26.9	2,320	43.2	3,160	14.3	1,200	53.7	2,840	16.4	1,440
K	22.5	......	42.5	......	27.5	......	25.0	......	42.5	......	45.0	......	70.0	......	52.5	......	......	......	......	......	25.0	......
7	26.5	......	34.0	......	37.0	......	37.0	......	42.3	......	36.3	......	32.5	......	31.5	......	26.5	......	......	......	......	......
8	26.3	1,220	18.7	900	43.8	1,600	21.9	1,270	45.3	2,310	14.4	1,000	46.3	2,530	48.0	3,490	23.8	1,420	......	......	19.4	1,130
9	23.4	1,460	27.1	1,800	34.0	1,820	25.4	1,440	38.3	2,080	......	......	42.0	2,160	44.8	2,560	26.7	1,480	......	......	35.7	1,920
C	22.2	......	20.1	......	43.2	......	24.7	......	45.1	......	24.0	......	52.8	......	50.0	......	......	......	......	......	37.8	......
11	30.0	......	36.1	......	45.6	......	45.4	......	48.4	......	45.2	......	48.2	......	49.6	......	36.5	......	......	......	30.4	......
12	35.0	......	50.0	......	51.5	......	50.3	......	57.5	......	50.0	......	52.5	......	46.2	......	50.0	......	......	......	......	......
I	31.8	2,370	38.1	2,335	45.2	2,820	31.4	2,475	50.5	3,025	26.4	2,500	46.0	3,195	57.3	3,920	......	......	......	......	39.8	2,770
14	40.0	2,500	38.5	3,400	48.5	3,210	28.0	3,400	43.7	2,890	32.7	3,740	47.3	5,780	50.1	6,120	40.9	2,550	44.9	4,080	......	......
15	47.2	......	50.0	......	64.3	......	61.4	......	70.0	......	55.7	......	68.6	......	64.3	......	55.7	......	67.5	......	......	......
16	46.6	2,570	47.4	2,630	46.0	2,730	16.4	2,680	53.0	2,810	55.0	2,950	58.4	3,090	62.0	3,260	54.3	3,050	......	......	53.6	2,930
11	46.8	......	50.3	......	60.1	......	67.8	......	60.3	......	72.0	......	71.0	......	70.0	......	......	......	......	......	61.8	......
18	50.0	3,160	48.3	2,900	55.6	3,500	50.0	3,240	58.3	3,500	53.6	3,340	58.3	3,540	57.8	4,280	57.5	3,400	63.9	4,000	52.8	3,400
19	56.5	......	62.8	......	68.7	......	64.2	......	76.4	......	63.0	......	68.6	......	70.9	......	58.4	......	......	......	54.2	......
20	61.7	......	62.5	......	73.3	......	64.3	......	67.0	......	66.0	......	72.5	......	76.0	......	68.0	......	......	......	67.0	......
Average	32.13	1,965	35.18	2,154	43.21	2,288	37.12	2,250	46.80	2,886	40.27	2,329	47.53	3,222	48.14	3,657	39.75	2,357	46.61	3,156	33.50	2,144

(*) In experiments G, K, C, I, and H 150 lbs., costing $5.62½. (†) In same experiments, 150 lbs., costing $1.50. (‡) *Kinds and amounts of farm manures.*—Experiment 1 stable manure, 20 loads; 5, stable manure, 500 cubic feet; 15, stable manure, 30 loads.

Yields per acre with other fertilizers.

No. 1. G. Clendon, Jr., Va. Finely ground raw South Carolina phosphate, 400 lbs. per acre. 29½ bushels per acre.

No. 9. J. W. Pierce, Mass. Sulphate of magnesia, 300 lbs. per acre, 27.7 bushels; sulphate of magnesia, 200 lbs., and 20 bushels wood ashes, 47.7 bushels; superphosphate and muriate of potash, as F, with addition of 200 lbs. sulphate of magnesia, 40.9 bushels.

No. 12. H. Gaylord, Conn. Wood ashes, 46.3 bushels.

No. 13. C. Fairchild, Conn. Bone dust, 200 lbs., 42.3 bushels; bone dust, 200 lbs., and muriate of potash, 150 lbs., 47.3 bushels; lime, 2,000 lbs., 39.6 bushels. See full report of Mr. Fairchild's experiment, Appendix A.

Number.	Experimenters.	Surface soil.			Subsoil.	Previous cropping.	Weather.			Fertilizers, how applied.
		Kind.	Texture.	Moisture.						
1	Geo. Clendon, jr., Buckner's Station, Va.	Clay loam	Compact	Dry	Red clay	Corn (1)		Dry	Favorable	Broadcast.
G	Prof. W. H. Jordan, Orono, Me	do	do	Medium.	Clay	Corn		do	Unfavor'ble.	Hill.
3	A. P. Arnold, Vineland, N. J	Sandy loam	Loose	Dry	Sand and gravel.	Sweet potatoes.	Cool	do	do	Broadcast.
4	Prof. John R. Page, University of Va.	Sandy	do	do	Sand and clay.	Wheat	do	do	do	Do.
5	John M. Manning, Taunton, Mass	Sandy loam	do	Medium.	Yellow sand	Corn	Warm.	Wet	Favorable	Do.
K	Wm. C. Newton, Durham, Conn	Dark loam	Fine	Moist	Yellow loam	Grass			do	Do.
7	C. G. Shenk, Bachmansville, Pa	Sand and gravel	Loose	Dry	Sand and gravel.	do	Warm.	Dry	Unfavor'ble.	Do.
8	R. P. Wolcott, Holland Patent, N. Y.	Sandy	Light and loose.	do	Sand	Pasture	do	Moist.	Favorable	Hill.
9	J. W. Pierce, West Milford, Mass	Clay loam	Compact	do	Clay and gravel.	Grass and corn	do	Dry	do	Broadcast.
C	W. I. Bartholomew, Putnam, Conn	Clay	Loose	Medium.	Compact	Corn			do	Drill.
11	Hiram Pitts, Washington, D. C	Sandy or grav. loam.	Light		Clay	Grass	Warm.	Dry	do	Broadcast.
12	Henry Gaylord, Cheshire, Conn	Sandy loam	Loose	Dry	Gravelly loam	Hay	do	do	do	Drill.
1	Chas. Fairchild, Middletown, Conn	do	Light and loose.	do	Sand and gravel.	Pasture	do	do	do	Hill.
14	John H. Pann, Middleboro', Mass	do	do	do		Clover		do	do	Drill.
15	Fairbanks & DeWitt, Rivings Mills, Md.	Clay and sand	Compact	Moist		Corn	Cool	Wet	do	Broadcast.
16	J. J. Whitson, Indiana	Clay	Heavy	Wet		do			Unfavor'ble.	Do.
H	Edward Hicks, Old Westbury, N. Y.	Sandy loam	Loose	Dry	Yellow loam	Pasture		Dry	Favorable	Drill.
18	C. L. Kauffman, Dillingersville, Pa	do	do	do	Gravelly	Grass	Warm.	Wet	do	Hill.
19	W. Eliason, Chestertown, Md	Gravelly loam	Compact	do	Clay	Wheat	do	Dry	do	Do.
20	M. H. Dean, Falls Village, Conn	Clay loam	Heavy	do	Gravel	Hay		do	do	Broadcast.

TABLE IX.—EXPERIMENTS WITH POTATOES, TURNIPS, AND OTHER CROPS, 1880.

Yields per acre with different fertilizers.

Number of experiment.	Number of fertilizer.	O.	A.	B.	C.	D.	E.	F.	G.	H.		OO.
	Fertilizers per acre.	No manure.	Nitrate of soda, 200 lbs.*	Dissolved bone-black, 300 lbs.	Muriate of potash, 200 lbs.†	Nitrate of soda, 150 lbs.; dissolved bone-black, 300 lbs.	Nitrate of soda, 150 lbs.; muriate of potash, 200 lbs.†	Dissolved bone-black, 300 lbs.; muriate of potash, 200 lbs.†	Nitrate of soda, 150 lbs.; dissolved bone-black, 300 lbs.; muriate of potash, 200 lbs.†	Plaster, 200 lbs.	Farm manures.	No manure.
	Cost per acre	....	$7 50	$5 25	$4 50	$10 88	$10 13	$9 75	$15 38	$0 80	Variable.	
21	Potatoes ....bu.	29.3	28.0	64.7	29.3	76.7	27.7	104.0	127.3	39.7	101.3	34.7
22	Potatoes ....bu.	72.5	71.7	100.2	72.0	109.2	57.3	98.0	....	....	....	
23	Potatoes ....bu.	46.0	51.0	46.0	46.5	48.5	46.0	50.0	41.0	41.0	....	37.0
C	Potatoes ....bu.	78.0	90.0	112.0	116.0	132.0	106.0	102.0	152.0	....	....	62.0
25	Potatoes ....bu.	136.7	240.0	166.7	174.7	....	....	....	260.0	200.0	....	130.0
26	Potatoes ....bu.	152.0	164.0	170.0	155.0	166.0	168.0	244.0	221.0	213.0	....	166.0
	Average of 4 experiments in 1880 (1) ....bu.	76.3	83.3	98.2	86.7	105.8	99.4	125.0	135.3	97.9	101.3	74.9
27	Sweet potatoes ....bu.	132.8	158.4	152.4	188.4	172.0	200.0	208.0	222 0	....	203.5	......
	Oats:											
28	Grain ....bu.	20.9	20.8	22.5	23.4	23.2	25.6	27.2	27.8	21.9		
28	Straw ....lbs.	960	1,045	1,000	820	1,090	1,100	1,020	1,270	920	....	......
29	Turnips ....bu.	....	....	320	340	410	500	400	500	300	....	270
30	Onions ....bu.	290	530	510	680	620	500	650	610	400	390	......

* In experiment C, which is the same as reported in Table II, special nitrogen experiments, 150 pounds, costing $5.62½.
† In same experiment, 150 pounds, costing $3.37½. (1) In computing averages of potato experiments Nos. 22 and 25 are omitted.

Yields per acre with other fertilizers.

No. 21. J. M. MANNING. Bone-flour, 300 pounds + wood ashes, 25 bushels 89 bushels (stable manure 5,000 cubic feet), yield as per table.
No. 27. A. P. ARNOLD, N. J. 20 loads of stable manure, yield as per table.
No. 30. W. A. BENEDICT, Conn. 20 tons stable manure, yield as per table.

Number.	Experimenters.	Surface soil.			Subsoil	Previous cropping.	Weather.			Fertilizers, how applied.
		Kind.	Texture.	Moisture.						
21	J. M. Manning, Taunton, Mass	Sandy loam	Light	Medium	Yellow sand	Grass	Variable	Variable		Broadcast.
22	E. B. Skeeves, Ives Grove, Wis	Black loam	do	Dry	Yellow clay	Flax	Warm	Wet	Variable	Drill.
23	E. C. Green, Granger, Ohio	Clayey loam	Loose	do	do	Corn	do	Dry	Very unfavorable	Broadcast.
C	W. I. Bartholomew, Conn	Clay	do	Medium	Compact	do			Favorable	Drill.
25	A. I. Wright, Peterboro, Ont	Sandy	do	Dry	Gravel and sand	Wheat	Cool	Wet		Broadcast.
26	M. H. Dean, Falls Village, Conn	Clayey loam	Heavy	do	Heavy	Hay		Dry	Favorable	Do.
27	A. P. Arnold, Vineland, N. J	Sandy loam	Loose	do	Clay and gravel	Sweet potatoes		do	do	Drill.
28	John C. Gundy, Lewisburg, Pa	Red gravel		do	Red rock	Corn	Warm	do	Very unfavorable	Broadcast.
29	M. H. Dean, Conn	Clayey loam	Heavy	do	Gravelly	Hay		do	Favorable	
30	W. A. Benedict, Conn	do	do	Medium	Yellow clay	Onions	Warm	do	Unfavorable	Do.

TABLE X.—*Effects of individual ingredients of fertilizers, nitro*

EXPLANATION.—This table is intended to show (1) the regularity or irregularity of the action of the potash, and plaster in the different plots of each experiment. Thus, in No. B, the superphosphate, The figures are found by subtracting the yield without each ingredient in each case from the yields gives the effect of superphosphate alone. That of mixture of superphosphate and potash salts, less the results for each material on the several plots, gives the effect of that material in the experiment

Grouping of soils. (By yields without fertilizers. Heaviest soil of each group above and lightest below.)		Number of experiment.	Average yield unmanured.	INCREASE WITH NITROGEN. Nitrogen, 32 lbs., over no manure.	Nitrogen, 24 lbs., + phosphoric acid, over phosphoric acid alone.	Nitrogen, 24 lbs., + potash, over potash alone.	Nitrogen, 24 lbs., + phosphoric acid and potash, over phosphoric acid and potash.	Average increase from nitrogen.
								EXPERIMENTS
Yielding less than 20 bushels of shelled corn per acre without manure.	Heavy clays to light sandy soils.	C	9.2	10.1	—5.3	6.6	13.7	6.3
		B	17.5	1.0	2.0	2.0	8.5	3.4
		2	7.0	10.5	6.2	5.8	—5.1	4.3
		3	6.5	—3.3	2.6	....	5.2	1.5
		4	9.5	8.5	5.0	....	8.0	7.0
		5	5.5	1.0	7.7	....	4.0	3.2
		6	17.5	2.4	12.5	....	5.0	6.6
		7	8.7	0.3	5.0	....	3.7	2.9
		8	7.5	—2.0	8.0	....	4.0	3.3
		9	5.0	6.0	7.5	8.5	5.0	6.8
		Average.	9.4	3.5	5.1	(5.5)	5.2	4.5
20–30 bushels shelled corn per acre without manure.	Heavy clays to light soils.	A	20.9	—3.6	17.7	10.0	2.8	6.7
		10	29.7	5.3	....	....	—2.5	1.3
		11	28.7	7.0	1.2	....	9.3	5.8
		12	26.3	8.8	16.9	....	18.7	13.1
		13	27.5	24.4	7.1	3.3	6.3	10.3
		14	20.2	20.3	10.5	7.0	—0.5	9.3
		15	20.5	23.2	2.6	—13.0	7.7	7.8
		16	24.0	—1.5	1.5	....	—1.0	—0.2
		Average.	24.9	10.5	6.6	(3.0)	5.4	6.8
30–40 bushels unmanured	Heavy to light.	17	33.6	7.4	8.3	....	10.0	8.0
		18	30.5	6.9	2.7	....	....	3.2
		19	33.0	—1.0	3.3	....	0.4	1.2
		20	32.8	9.0	17.7	....	7.5	11.4
		Average.	32.5	5.6	8.0	....	4.5	6.0
Over 40 bushels unmanured......	Heavier to lighter.	21	45.1	13.2	6.0	—20.3	11.0	1.6
		22	49.7	8.2	7.3	....	1.0	6.4
		23	64.9	—1.8	1.2	4.8	11.3	4.0
		24	45.7	14.7	0.3	....	18.7	10.1
		Average.	51.3	8.6	3.7	(—7.8)	10.5	5.5
Total averages of 26 experiments.		....	....	5.8	5.6	....	5.7	5.7
								EXPERIMENTS WITH
Ranging from heavy clay to sandy loam.		25	137.5	—10.5	27.0	—14.0	23.0	6.4
		26	31.2	—0.4	8.8	....	—0.8	2.5
		27	130.0	32.0	10.0	....	30.0	24.0
		28	105.0	—0.3	45.0	....	23.0	22.6
		29	60.0	16.6	6.6	....	20.0	14.4
		30	133.0	6.0	11.0	—23.0	35.0	7.0
		31	141.0	—8.0	41.0	....	22.9	18.6
		32	121.0	—4.0	8.0	....	22.0	8.7
		33	32.5	7.5	20.0	40.0	40.0	26.9
Total averages of 9 experiments..		....	....	4.3	19.7	....	23.9	14.6

*That is with superphosphate, which

gen, phosphoric acid (with sulphuric acid and lime), and potash.

different materials and (2) the specific effects of the substances furnishing nitrogen, phosphoric acid, and in No. C, the muriate of potash, is uniformly efficient. In No. 21 the results are very irregular. in the cases in which it was used. Thus, the yield with superphosphate alone, minus that with nothing, that with potash alone, gives the effect of superphosphate with potash salts, and so on. Averaging as a whole.

INCREASE WITH PHOSPHORIC ACID.						INCREASE WITH POTASH.				
Phosphoric acid, 48 lbs., over no manure.	Phosphoric acid, 48 lbs., + nitrogen, over nitrogen alone.	Phosphoric acid, 48 lbs., + potash, over potash alone.	Phosphoric acid, 48 lbs., + nitrogen, + potash, over nitrogen + potash.	Average increase from phosphoric acid.	Increase with plaster (= sulphuric acid and lime) over no manure.	Potash, 100 lbs., over no manure.	Potash, 100 lbs., + nitrogen, over nitrogen alone.	Potash, 100 lbs., + phosphoric acid, over phosphoric acid alone.	Potash, 100 lbs., + nitrogen, + phosphoric acid, over nitrogen + phosphoric acid.	Average increase from potash.
WITH CORN, 1878										
5.1	—10.3	8.0	15.1	6.0	....	51.0	47.4	53.8	72.8	56.3
22.2	32.2	24.0	30.5	25.0	....	1.4	2.4	3.2	9.7	4.2
3.3	—1.0	9.4	—1.5	2.6	7.4	2.2	—2.5	8.2	—0.3	1.3
16.5	22.4	16.4	....	18.5	4.1	—0.7	....	—0.8	—1.8	0.1
1.5	—2.0	6.0	....	1.3	—0.5	32.5	24.0	37.0	40.0	33.0
5.2	16.9	6.7	....	9.5	3.9	2.3	....	3.8	2.1	2.1
16.0	26.3	12.5	....	18.2	....	8.5	....	5.0	—2.5	5.7
8.8	13.5	8.8	....	10.2	—1.7	—1.2	....	—1.2	—2.5	—2.1
13.2	23.2	16.2	....	17.5	....	0.1	....	3.1	1.3	0.5
3.5	6.0	6.5	....	4.8	10.0	14.0	....	17.5	16.0	13.8
9.5	12.7	11.5	(14.7)	11.3	1.8	11.1	17.7	13.0	13.6	11.5
6.2	17.7	7.4	—2.1	7.9	....	10.0	23.6	10.9	2.8	12.4
7.5	....	2.5	....	3.3	—2.4	5.0	—25.0	....	—2.5	....
5.3	3.1	6.3	....	6.1	3.8	2.8	....	4.4	13.5	8.3
23.2	32.3	32.3	....	29.2	29.3	8.8	....	17.9	18.7	15.1
12.5	—4.8	—1.7	13.0	1.5	12.5	22.4	—0.5	9.9	6.6	9.9
37.0	27.4	41.0	33.5	34.7	2.8	10.0	—2.5	13.8	2.6	6.0
32.2	2.6	—6.5	15.1	6.9	12.5	19.4	—17.7	—10.3	—5.2	—3.4
5.5	13.5	11.5	....	10.2	2.0	—3.5	....	13.5	—1.0	3.0
16.2	11.5	11.7	(14.9)	12.5	8.6	9.4	0.1	7.5	4.4	6.4
0.4	1.2	—1.1	....	—0.3	—1.6	11.6	....	3.0	9.3	7.4
6.1	2.1	7.7	....	5.3	0.5	4.5	....	6.1	3.4	4.7
—1.0	2.4	0.3	10.0	2.9	—6.0	6.3	—2.0	8.6	5.6	6.2
....	6.7	19.5	....	8.7	6.2	12.5	....	32.0	26.8	22.7
1.4	3.1	6.6	(10.0)	4.2	—0.2	8.7	—2.0	12.4	11.3	10.3
17.5	10.0	—11.0	20.6	8.4	—2.5	25.1	—8.4	—3.4	12.0	3.7
6.2	4.7	4.6	....	6.1	3.3	8.6	....	7.0	7.0	6.3
—0.2	2.4	4.8	11.5	6.2	0.8	—0.6	5.6	4.6	14.0	6.1
8.7	—6.3	19.5	....	6.0	2.6	—7.5	....	3.3	21.7	4.4
8.1	2.7	15.3	(16.1)	6.7	1.1	5.1	—1.4	2.9	11.4	5.1
8.9	8.7	9.6	(9.0)	9.0	4.3	8.7	9.2	9.4	9.5	9.2
POTATOES, 1878.										
—9.5	27.0	—21.0	16.0	3.1	—5.5	—1.5	—5.0	—12.0	—16.0	—8.6
—2.8	6.4	7.4	....	4.0	4.0	37.8	....	48.0	38.4	41.4
70.0	48.0	95.0	....	71.0	11.0	—5.0	....	20.0	40.0	18.5
....	48.0	22.0	....	23.3	23.3	35.0	....	57.0	35.0	42.3
40.0	30.0	56.7	....	42.2	42.2	33.3	....	50.0	63.4	48.9
5.0	10.0	5.0	63.0	20.8	20.8	16.0	—2.0	27.0	51.0	23.0
24.0	73.0	38.5	....	45.2	45.2	65.0	....	82.5	64.4	70.6
47.0	59.0	—69.0	....	12.3	12.3	55.0	....	—23.0	—9.0	7.7
47.5	60.0	80.0	80.0	66.9	66.9	67.5	20.0	20.0	40.0	49.2
24.6	40.2	23.8	....	32.1	12.1	33.7	....	29.9	34.1	32.6

had also some sulphuric acid and lime.

TABLE X—

Grouping of soils. (By yields without fertilizers. Heavier soil of each group above and lighter below.)		Number of experiment.	Average yield unmanured.	INCREASE WITH NITROGEN. Nitrogen, 32 lbs., over no manure.	Nitrogen, 24 lbs., + phosphoric acid, over phosphoric acid alone.	Nitrogen, 24 lbs., + potash, over potash alone.	Nitrogen, 24 lbs., + phosphoric acid and potash, over phosphoric acid and potash.	Average increase from nitrogen.
EXPERIMENTS								
Yielding less than 20 bushels of shelled corn per acre without manure.	Heavier to lighter soils.	1	18.5	1.8	—1.1	—4.4	2.5	—0.3
		C	8.1	—0.7	4.9	—0.6	3.7	1.8
		3	3.3	—0.6	.... ..	—1.2	—3.0	—1.2
		4	19.7	4.5	9.0	3.0	6.2	5.7
		5	3.7	[33.9]	15.2	9.5	—11.0	11.9
		6	8.0	6.7	15.4	8.8	40.0	17.2
		7	8.1	—1.3	1.1	0.1	4.9	1.2
		8	11.3	—0.1	2.3	—0.1	2.6	0.9
		9	12.5	25.0	—18.7	13.0	....	4.8
		F	7.7	—1.5	13.5	—2.0	—7.2	0.7
		Av'ge.	9.2	6.7	4.1	2.4	4.3	4.1
20–30 bushels shelled corn per acre without manure.	Heavier to lighter soils.	11	23.9	—7.9	18.0	3.3	16.1	7.6
		12	14.3	8.0	17.0	19.7	—5.2	9.8
		13	21.9	5.6	—3.7	5.0	7.5	3.6
		14	22.7	13.8	5.1	—3.6	8.9	6.0
		15	25.4	3.4	3.7	—10.0	24.1	10.0
		Av'ge.	21.6	1.5	8.0	6.8	10.1	7.4
30–40 bushels unmanured..........	Heavier to lighter soils.	16	32.5	15.0	10.0	—13.8	....	2.8
		17	41.0	3.0	—14.0	7.0	....	—1.0
		18	34.0	—9.7	—0.1	—7.2	—12.9	—7.7
		19	25.8	10.1	—6.4	0.7	—0.8	—0.9
		20	33.0	—2.0	....	....	....	—0.5
		21	36.8	24.1	14.2	—11.6	3.3	7.5
		22	37.8	15.5	15.1	22.6	6.2	18.5
		Av'ge.	34.3	8.0	2.7	—0.2	—0.6	2.7
Over 40 bushels unmanured........	Heavier to lighter.	23	46.7	5.3	—14.5	—6.0	7.0	—2.0
		E	43.1	6.1	—4.9	—1.0	—2.6	—0.6
		25	41.7	17.9	14.8	18.9	23.0	18.4
		26	44.0	16.0	—8.8	1.3	20.0	7.1
		Av'ge.	43.8	11.3	—5.8	3.3	11.8	5.7
Average of 26 experiments........		....	24.0	6.3	1.7	2.5	5.5	4.6
EXPERIMENTS								
Ranging from heavy clay to sandy loam.		27	37.0	12.0	9.0	—14.0	18.0	6.2
		C	46.0	4.0	36.0	6.0	15.0	13.2
		29	41.0	—9.0	32.0	9.0	11.0	10.8
		30	37.0	8.0	—19.0	—5.0	27.0	27.0
		31	150.0	30.0	45.0	45.0	10.0	32.0
		33	63.0	....	—14.0	—10.0	—1.0	—6.2
		34	40.0	16.0	2.0	—6.0	10.0	5.5
		35	29.0	56.0	15.0	17.0	—4.0	21.0
		36	80.0	25.0	15.0	—50.0	65.0	13.7
		37	157.0	—90.0	—4.0	—15.0	45.0	—16.0
Total averages of 9 experiments..		....	52.8	22.5	4.4	—1.6	20.1	11.3

Continued.

INCREASE WITH PHOSPHORIC ACID (plus sulphuric acid and lime).					INCREASE WITH PLASTER.	INCREASE WITH POTASH.				
Phosphoric acid, 48 lbs., over no manure.	Phosphoric acid, 48 lbs., + nitrogen, over nitrogen alone.	Phosphoric acid, 48 lbs., + potash, over potash alone.	Phosphoric acid, 48 lbs., + nitrogen, + potash, over nitrogen + potash.	Average increase from phosphoric acid.	Sulphuric acid and lime, over no manure.	Potash, 100 lbs., over no manure.	Potash, 100 lbs., + nitrogen, over nitrogen alone.	Potash, 100 lbs., + phosphoric acid, over phosphoric acid alone.	Potash, 100 lbs., + nitrogen, + phosphoric acid, over nitrogen + phosphoric acid.	Average increase from potash.
WITH CORN, 1879.										
1.8	—1.1	0.3	7.2	2.0	—5.5	—1.2	—7.4	—2.7	0.9	—2.6
28.4	34.0	34.3	38.6	33.8	....	—0.4	—0.3	5.5	4.3	2.2
8.7	9.3	10.0	8.2	9.0	—4.6	—3.4	2.8	4.7	1.7	3.1
2.6	7.1	16.2	19.4	11.3	11.1	—3.7	—9.8	—4.9	2.1	6.5
10.9	—7.8	3.2	0.4	1.7	—28.0	3.2	—19.2	—4.5	11.0	—7.9
15.3	24.0	10.8	42.0	23.0	2.6	21.4	23.5	16.9	41.5	25.8
11.6	10.9	11.3	16.1	12.9	11.1	1.9	3.7	5 1	8.9	4.9
5.3	7.7	2.3	5.9	5.2	—6.8	—0.3	—1.2	—3.3	—3.0	—1.9
28.7	—15.5	20.0	7.0	10.2	25.9	12.5	0.5	3.8	22.5	9.8
—0.3	13.7	9.0	3.8	6.5	....	33.6	32.5	43.3	22.6	33.0
11.3	7.2	11.7	14.8	11.5	0.6	6.3	2.9	7.3	8.9	6.3
2.3	28.2	10.4	23.2	16.0	—4.9	—12.9	—1.7	—4.8	—6.7	—6.5
6.7	14.7	....	—24.9	—0.9	—0.3	10.3	22.0	4.6	—17 6	4.8
11.8	2.5	7.5	10.0	7.9	12.6	1.8	1.2	—2.5	8.7	2.3
26.7	18.2	10.4	22.9	19.5	....	23.0	5.8	6.7	10.5	11.5
3.4	10.3	—3.7	10.4	5.1	12.6	11.7	25.1	5.2	25.2	16.7
10.2	14.7	6.1	10.1	9.5	4.0	6.7	10.6	1.8	4.0	5.7
7.5	2.5	—12.5	—1.3	—0.9	—2.5	22.5	—6.3	2.5	—8.8	2.7
43.0	26.0	21.0	14.0	26.0	3.0	2.0	6.0	—20.0	—6.0	—4.5
11.7	21.3	17.0	11.3	15.3	12.2	—2.4	0.1	2.9	—9.9	2.1
8.1	—7.4	1.5	....	0.2	2.3	2.1	7.5	—5.7	—0.1	0.4
34.5	....	....	....	8.6	38.8	1.5	....	....	....	0.4
11.8	1.9	—3.1	11.8	5.6	0.1	26.7	—9.0	11.8	0.9	12.6
16.7	16.3	16.9	0.5	13.9	20.9	21.8	28.9	22.0	13.1	22.7
16.4	8.6	5.6	9.4	9.8	10.7	10.6	3.9	1.6	—1.5	4.5
14.3	—4.5	14.0	27.0	12.7	17.3	7.8	—3.5	7.5	28.0	9.7
2.9	—8.1	4.4	2.8	0.4	....	15.9	8.8	17.4	19.7	15.4
0.5	—2.6	0.9	....	0.4	—4.2	—0.6	—0.4	—7.5	3.0	—1.4
29.8	5.0	5.0	23.7	14.8	1.0	12.2	—2.5	—12.6	16.2	3.3
11.8	2.5	6.1	17.5	7.1	3.5	8.8	—0.6	1.2	16.7	6.8
12.9	8.3	8.1	11.7	10.2	5.1	8.7	4.1	3.7	8.1	6.2
WITH POTATOES, 1879.										
1.0	—2.0	38.0	70.0	29.2	2.0	36.0	10.0	73.0	82.0	50.2
32.0	72.0	69.0	78.0	62.7	....	....	10.0	37.0	16.0	15.7
21.0	64.0	65.0	67.0	54.3	14.0	—8.0	10.0	36.0	13.0	12.7
99.0	72.0	96.0	128.0	98.7	4.0	12.0	—1.0	9.0	55.0	18.7
25.0	40.0	145.0	110.0	80.0	0.0	65.0	80.0	185.0	150.0	120.0
4.0	—6.0	—13.0	—4.0	—4.7	4.0	3.0	—3.0	14.0	—1.0	—3,7
12.0	—2.0	16.0	32.0	14.5	20.0	32.0	10.0	36.0	44.0	40.5
40.0	—1.0	38.0	17.0	23.5	26.0	9.0	—30.0	7.0	—12.0	—6.5
30.0	—11.0	—95.0	20.0	—14.0	10.0	95.0	20.0	—30.0	51.0	3.4
27.0	105.0	75.0	35.0	60.5	20.0	—60.0	15.0	—4.0	45.0	—1.0
36.0	17.9	35.9	57.6	36.3	16.4	32.4	7.3	32.3	48.0	30.2

TABLE X—

Grouping of soils.	Number of experiment.	Average yield unmanured.	Increase with nitrogen. Nitrogen, 32 lbs., over no manure.	Nitrogen, 24 lbs., + phosphoric acid, over phosphoric acid alone.	Nitrogen, 24 lbs., + potash, over potash alone.	Nitrogen 24 lbs., + phosphoric acid and potash, over phosphoric acid and potash.	Average increase from nitrogen.
EXPERIMENTS WITH							
Arranged in order of yield on unfertilized plots.	1	9.7	—1.6	8.9	1.9	....	3.1
	G	9.9	0.4	4.4	....	7.9	4.2
	3	12.2	3.4	—18.5	2.8	10.9	—0.4
	4	16.2	—4.1	—5.0	1.1	0.0	2.1
	5	19.6	3.3	12.6	—3.2	0.7	3.4
	K	23.8	19.9	14.7	19.7	30.0	21.1
	7	26.5	7.5	5.3	—6.0	0.0	1.7
	8	28.0	—6.9	3.0	—6.0	2.5	—1.9
	9	29.6	0.6	0.2	....	5.1	1.5
	C	30.0	—2.1	—0.3	—5.1	—5.1	—3.2
	11	30.2	5.6	2.8	—0.2	1.4	2.4
	12	35.0	15.0	6.0	—0.3	—6.3	3.6
	I	36.4	5.2	4.1	—4.9	10.0	3.6
	14	40.0	13.3	5.2	4.7	—9.2	3.6
	15	47.2	2.8	5.7	—5.7	—4.3	—0.4
	16	50.1	—2.7	7.2	1.3	3.5	2.3
	H	51.8	—3.5	0.0	4.2	—1.0	1.7
	18	52.0	—3.7	2.9	3.6	—0.5	0.6
	19	55.3	7.4	8.2	—1.2	2.3	4.2
	20	64.3	—1.6	—5.9	1.7	3.5	—0.6
Average of 26 experiments	....	33.4	2.9	3.1	0.4	2.7	2.6
EXPERIMENTS WITH							
	21	32.0	—1.8	10.8	—2.5	22.9	7.4
	22	72.5	5.2	9.0	—15.1	....	—0.3
	23	44.7	5.3	2.6	—0.6	—0.4	1.7
	C	78.0	12.0	0.0	—4.0	38.0	11.5
	25	152.8	89.5	....	....	....	89.5
	26	159.0	10.4	2.9	9.9	—24.5	—0.3
Average of 4 experiments	....	76.4	6.5	4.6	1.8	9.3	5.6
EXPERIMENTS WITH							
	27	117.6	21.7	12.1	4.0	10.2	12.0
EXPERIMENTS							
	28	20.9 960.0	—0.5 35.0	0.6 90.0	2.2 280.0	0.6 250.0	0.7 176.0
EXPERIMENTS							
	29	270.0	....	90.0	160.0	100.0	117.0
EXPERIMENTS							
	30	290.0	240.0	90.0	180.0	—40.0	117.5

Continued.

INCREASE WITH PHOSPHORIC ACID (plus sulphuric acid and lime).					INCREASE WITH PLASTER.	INCREASE WITH POTASH.				
Phosphoric acid, 48 lbs., over no manure.	Phosphoric acid, 48 lbs., + nitrogen, over nitrogen alone.	Phosphoric acid, 48 lbs., + potash, over potash alone.	Phosphoric acid, 48 lbs., + nitrogen, + potash, over nitrogen + potash.	Average increase from phosphoric acid.	Sulphuric acid and lime, over no manure.	Potash, 100 lbs., over no manure.	Potash, 100 lbs., + nitrogen, over nitrogen alone.	Potash, 100 lbs., + phosphoric acid, over phosphoric acid alone.	Potash, 100 lbs., + nitrogen + phosphoric acid, over nitrogen + phosphoric acid.	Average increase from potash.
CORN, 1880.										
9.7	20.2	9.9	....	13.3	....	0.3	2.2	−1.1	....	0.3
13.1	17.1	11.0	....	13.7	....	2.2	....	0.1	3.7	....
18.1	−2.2	−10.6	−2.8	0.6	13.3	9.5	8.9	−19.2	8.3	1.9
14.5	18.1	13.1	11.4	14.3	2.5	1.5	6.7	0.1	0.0	2.1
−2.2	7.1	0.1	3.8	2.2	−2.8	8.4	1.9	10.5	1.4	5.6
4.8	−0.4	−3.0	7.3	2.2	....	2.2	2.0	−5.2	9.7	3.7
10.5	8.3	−5.5	−4.8	2.1	0.0	10.5	2.3	−5.5	−10.8	−0.9
19.0	28.9	26.7	35.2	27.5	3.6	−2.1	−1.2	5.6	5.1	1.9
8.6	8.2	13.3	....	10.0	−4.9	−2.1	....	2.6	7.5	2.7
21.0	22.8	21.4	21.4	21.7	....	2.5	−0.5	2.9	−1.9	0.8
15.4	12.6	2.8	4.4	8.8	6.3	15.2	9.4	2.6	1.2	7.1
16.5	17.5	2.2	−3.8	8.1	15.0	15.3	0.0	1.5	−11.3	1.1
12.2	11.1	14.3	30.2	17.0	....	−2.4	−2.1	−0.3	6.6	0.5
8.5	5.2	19.3	17.4	12.6	0.9	−12.0	−5.8	−1.2	6.4	−3.2
17.1	20.0	7.2	8.6	13.2	10.5	14.2	5.7	4.3	−5.7	4.6
−4.1	5.8	4.7	6.9	3.3	4.2	3.7	7.7	12.5	8.8	8.2
13.6	10.0	3.2	−2.0	8.3	.....	21.0	21.7	10.6	9.7	15.8
3.4	10.0	8.3	4.2	6.5	5.5	−2.0	5.3	10.0	−0.5	3.2
13.4	14.2	4.4	7.9	10.0	3.1	8.9	0.3	−0.1	−6.0	0.8
9.0	4.7	8.2	10.0	8.0	3.7	0.0	3.3	−0.8	8.6	2.8
11.1	12.0	7.5	8.6	10.2	4.4	4.7	3.8	1.5	4.0	3.1
POTATOES, 1880.										
34.8	46.4	72.9	98.3	63.1	6.3	−1.4	−2.1	36.7	48.8	20.5
33.8	37.6	26.4	....	32.6	....	5.5	−14.8	−1.9	....	3.7
−0.3	2.4	3.4	−4.4	0.4	−4.7	0.9	−5.0	4.0	1.8	0.4
34.0	22.0	−2.0	40.0	23.5	....	38.0	22.0	2.0	40.0	25.5
2.3	....	....	....	2.3	28.7	3.5	....	....	....	3.5
4.9	−2.6	84.3	49.9	34.1	48.5	−1.7	−2.2	77.7	50.3	31.0
18.5	17.6	46.6	47.1	31.7	12.5	9.0	4.3	32.1	39.5	23.2
SWEET POTATOES, 1880.										
12.0	2.4	8.3	14.5	9.3	....	44.3	26.6	40.6	38.7	37.6
WITH OATS, 1880.										
1.6	2.7	3.8	2.2	2.6	−0.9	2.5	5.2	4.7	4.7	4.3
40.0	45.0	200.0	170.0	114.0	−40.0	−140.0	55.0	20.0	180.0	29.0
WITH TURNIPS, 1880.										
50.0	....	60.0	0.0	36.7	30.0	70.0	180.0	80.0	90.0	105.0
WITH ONIONS, 1880.										
220.0	90.0	−30.0	110.0	97.5	110.0	390.0	−30.0	140.0	−10.0	122.5

TABLE X—

	Number of experiment.	Average yield unmanured.	INCREASE WITH NITROGEN.				
			Nitrogen, 32 lbs., over no manure.	Nitrogen, 24 lbs., +phosphoric acid, over phosphoric acid alone.	Nitrogen, 24 lbs., +potash, over potash alone.	Nitrogen, 24 lbs., + phosphoric acid and potash, over phosphoric acid and potash.	Average increase from nitrogen.
							EXPERIMENTS
	C	7.3	1.2	4.3	—4.5	3.6	1.2
	L	12.5	10.0	10.0	8.8	9.5	9.6
	M	38.2	—2.3	—2.8	0.0	2.8	—0.6
	N	40.0	4.3	1.7	—3.7	—2.9	—0.6
	O	10.3	1.4	—1.7	5.3	—0.6	1.1
	P	16.3	9.7	1.7	—5.0	0.8	1.8
	Q	44.7	8.4	10.4	—8.4	—0.2	2.5
Average of 7 experiments	......	24.2	4.7	3.4	0.0	1.9	2.6
							EXPERIMENTS
	C, '81	44.0	4.0	0.0	2.0	26.0	8.0
	I, '81	28.0	14.0	38.7	8.0	34.0	23.7
	M, '81	12.8	29.9	—32.0	—3.2	24.7	4.9
Average of 5 experiments	......	28.2	15.9	2.2	2.2	28.2	12.2
							EXPERIMENTS
	I, '81	26.9	11.2	18.1	11.2	20.6	15.3
							EXPERIMENTS
	R, '81	587	218	437	368	322	336
							EXPERIMENTS
	S, '81	480	220	—120	—380	60	—55

Concluded.

INCREASE WITH PHOSPHORIC ACID (plus sulphuric acid and lime).					INCREASE WITH POTASH.				
Phosphoric acid, 48 lbs., over no manure.	Phosphoric acid, 48 lbs., + nitrogen, over nitrogen alone.	Phosphoric acid, 48 lbs., + potash, over potash alone.	Phosphoric acid, 48 lbs., + nitrogen, + potash, over nitrogen + potash.	Average increase from phosphoric acid.	Potash, 100 lbs., over no manure.	Potash, 100 lbs., + nitrogen, over nitrogen alone.	Potash, 100 lbs., + phosphoric acid, over phosphoric acid alone.	Potash, 100 lbs., + nitrogen + phosphoric acid over nitrogen + phosphoric acid.	Average increase from potash.
WITH CORN, 1881.									
5.1	8.2	15.2	23.3	12.9	2.7	—3.0	12.8	12.1	6.1
10.0	1.3	—1.2	—0.5	2.4	2.5	1.3	0.0	—0.5	0.8
—1.8	—2.3	0.0	2.8	—0.3	—3.7	—2.3	—1.9	3.7	—1.0
8.6	6.0	3.4	4.2	5.5	8.6	0.6	3.4	—1.2	2.8
5.7	2.6	16.9	11.0	9.0	7.4	11.3	18.6	19.7	14.3
6.5	—1.5	—6.3	0.5	0.4	18.2	3.5	5.4	4.4	7.9
6.5	8.5	7.0	15.2	9.3	7.3	—9.5	7.8	—2.8	0.7
5.8	3.3	5.0	7.9	9.5	6.1	—1.2	6.5	5.1	4.2
WITH POTATOES, 1881.									
14.0	10.0	24.0	48.0	24.0	6.0	4.0	16.0	42.0	17.0
28.0	52.7	30.7	56.7	42.0	32.0	16.0	34.7	30.7	28.4
4.3	—32.0	4.8	32.7	2.4	3.7	—36.8	—3.2	27.9	—2.1
15.4	10.2	19.8	45.8	22.8	13.9	—5.6	15.8	33.5	14.4
WITH OATS, 1881.									
6.9	13.8	2.5	11.9	8.8	4.4	4.4	0.0	2.5	2.8
WITH COTTON, 1881.									
575	794	655	609	658	—23	127	57	—58	26
WITH CLOVER, 1881.									
720	380	200	640	485	460	—140	—60	120	95

TABLE XI.—*Effects of individual ingredients.*

[Selected experiments.]

Date.	Number of experiment.	Average yield unmanured.	INCREASE WITH NITROGEN. Nitrogen, 32 lbs., over no manure.	Nitrogen, 24 lbs., + phosphoric acid, over phosphoric acid alone.	Nitrogen, 24 lbs., + potash, over potash alone.	Nitrogen, 24 lbs., + phosphoric acid and potash, over phosphoric acid and potash.	Average increase from nitrogen.	INCREASE WITH PHOSPHORIC ACID (plus sulphuric acid and lime). Phosphoric acid, 48 lbs., over no manure.	Phosphoric acid, 48 lbs., + nitrogen, over nitrogen alone.	Phosphoric acid, 48 lbs., + potash, over potash alone.	Phosphoric acid, 48 lbs., + nitrogen, + potash, over nitrogen + potash.	Average increase from phosphoric acid.	INCREASE WITH PLASTER. Sulphuric acid and lime, over no manure.	INCREASE WITH POTASH. Potash 100 lbs., over no manure.	Potash, 100 lbs., + nitrogen, over nitrogen alone.	Potash, 100 lbs., + phosphoric acid, over phosphoric acid alone.	Potash, 100 lbs., + nitrogen + phosphoric acid, over nitrogen + phosphoric acid.	Average increase from potash.
							EXPERIMENTS WITH CORN.											
1878	D	9.2	10.1	—5.3	6.6	13.7	6.3	5.1	—10.3	8.0	15.1	6.0	....	51.0	47.4	53.8	72.8	56.3
	B	17.5	1.0	2.0	2.0	8.5	3.4	22.2	32.2	24.0	30.5	25.0	....	1.4	2.4	3.2	9.7	4.2
	3	6.5	—3.3	2.6	0.0	5.2	1.5	16.5	22.4	16.4	....	18.5	4.1	—0.7	....	—0.8	—1.8	0.1
	4	9.5	8.5	6.0	....	8.0	7.0	1.5	—2.0	6.0	....	1.3	—0.5	32.5	24.0	37.0	40.0	33.0
	8	7.5	—2.0	8.0	....	4.0	3.3	13.2	23.2	16.2	....	17.5	....	0.1	....	3.1	1.3	0.5
	9	5.0	6.0	7.5	8.5	5.0	6.8	3.5	6.0	6.5	....	4.8	10.0	14.0	....	17.5	16.0	13.8
	12	26.3	8.8	16.9	....	18.7	13.1	23.2	32.3	32.3	....	29.2	29.3	8.8	....	17.9	18.7	15.1
1879	C	8.1	—0.7	4.9	—0.6	3.7	1.8	28.4	34.0	34.3	38.6	33.8	....	—0.4	—0.3	5.5	4.3	2.2
	6	8.0	6.7	15.4	8.8	40.0	17.2	15.3	24.0	10.8	42.0	23.0	2.6	21.4	23.5	16.9	41.5	25.8
	7	8.1	—1.3	1.1	0.1	4.9	1.2	11.6	10.9	11.3	16.1	12.9	11.1	1.9	3.7	5.1	8.9	4.9
	F	7.7	—1.5	13.5	—2.0	—7.2	0.7	0.3	13.7	9.0	3.8	6.5	....	33.6	32.5	43.3	22.6	33.0
	14	22.7	13.8	5.1	—3.6	8.9	6.0	26.7	18.2	10.4	22.9	19.5	....	23.0	5.8	6.7	10.5	11.5
	22	37.8	15.5	15.1	22.6	6.2	18.5	16.7	16.3	16.9	0.5	13.5	20.9	21.8	28.9	22.0	13.1	22.7
	E	43.1	6.1	—4.9	—1.0	—2.6	—0.6	2.9	—8.1	4.4	2.8	0.4	....	15.9	8.8	17.4	19.7	15.4
	25	41.7	17.9	14.8	18.9	23.0	18.4	0.5	—2.6	0.9	0.0	0.4	—4.2	—0.6	—0.4	—7.5	3.0	—1.4
1880	K	23.8	19.9	14.7	19.7	30.0	21.1	4.8	—0.4	—3.0	7.3	2.2	....	2.2	2.0	—5.2	9.7	3.7
	C	30.0	—2.1	—0.3	—5.1	—5.1	—3.2	21.0	22.8	21.4	21.4	21.7	....	2.5	—0.5	2.9	—1.9	0.8
	11	30.2	5.6	2.8	—0.2	1.4	2.4	15.4	12.6	2.8	4.4	8.8	6.3	15.2	9.4	2.6	1.2	7.1
	15	47.2	2.8	5.7	—5.7	—4.3	—0.4	17.1	20.0	7.2	8.6	13.2	10.5	14.2	5.7	4.3	—5.7	4.6
	H	51.8	—3.5	0.0	4.2	—1.0	1.7	13.6	10.0	3.2	—2.0	8.3	....	21.0	21.7	10.6	9.7	15.8
	19	55.3	7.4	8.2	—1.2	2.3	4.2	13.4	14.2	4.4	7.9	10.0	3.1	8.9	0.3	—0.1	—6.0	0.8
1881	C	7.3	1.2	4.3	—4.5	3.6	1.2	5.1	8.2	15.2	23.3	12.9	....	2.7	—3.0	12.8	12.1	6.1
	L	12.5	10.0	10.0	8.8	9.5	9.6	10.0	1.3	—1.2	—0.5	2.4	....	2.5	1.3	2.0	—0.5	0.8
	O	10.3	1.4	—1.7	5.3	—0.6	—1.1	5.7	2.6	16.9	11.0	9.0	....	7.4	11.3	18.6	19.7	14.3
Average..........	....	21.9	4.7	5.8	3.4	7.3	5.8	12.1	12.1	11.4	10.2	12.1	3.9	12.1	9.1	12.0	13.2	12.1

EXPERIMENTS WITH POTATOES.

1878	26	31.2	—0.4	8.8	....	0.8	2.5	—2.8	6.4	7.4	....	4.0	4.0	37.8	....	48.0	38.4	41.4
	27	130.0	32.0	10.0	....	30.0	24.0	70.0	48.0	95.0	....	71.0	11.0	—5.0	....	20.1	40.0	18.5
	28	105.0	—0.3	45.0	....	23.0	22.6	00.0	48.0	22.0	....	23.3	23.3	35.0	....	57.0	35.0	42.3
	29	60.0	16.6	6.6	....	20.0	14.4	40.0	30.0	56.7	....	42.2	12.2	33.3	....	50.0	63.4	48.9
	31	141.0	—8.0	41.0	....	22.9	18.6	24.0	73.0	38.5	....	45.2	45.2	65.0	....	82.5	64.4	70.6
	33	32.5	7.5	20.0	40.0	10.0	26.9	47.5	60.0	80.0	80.0	66.9	66.9	67.5	20.0	20.0	40.0	49.2
1879	31	150.0	30.0	45.0	45.0	10.0	32.0	25.0	40.0	145.0	110.0	80.0	....	65.0	80.0	185.0	150.0	120.0
	34	40.0	16.0	2.0	—6.0	10.0	5.5	12.0	—2.0	16.0	32.0	14.5	20.0	32.0	10.0	36.0	44.0	40.5
1880	21	32.0	—1.8	10.8	—2.5	22.9	7.4	34.8	46.4	72.9	98.3	63.1	6.3	—1.4	—2.1	36.7	48.8	20.5
	C	70.0	12.0	2.0	0.5	39.3	13.5	34.0	24.2	5.8	44.6	27.2	....	38.0	26.5	9.8	46.9	30.8
1881	C	44.0	4.0	0.0	2.0	26.0	8.0	14.0	10.0	24.0	48.0	24.0	....	6.0	40.0	16.0	42.0	17.0
	1	28.9	14.0	38.7	8.0	34.0	23.7	28.0	52.7	—30.7	56.7	42.0	....	32.0	16.0	34.7	30.7	28.4
Average	....	63.4	10.2	19.1	7.2	26.2	16.6	27.1	36.4	32.7	39.1	41.1	18.4	33.3	15.8	49.6	53.6	44.0

TABLE XII.—*Averages of results of experiments of* 1878, 1879, 1880, *and* 1881.

	Kinds and amounts of fertilizing materials applied per acre.	0. No manure.	A. Nitrate of soda, 200 lbs.	B. Dissolved bone-black, 300 lbs.	C. Muriate of potash, 200 lbs.	D Nitrate of soda, 150 lbs.; dissolved bone-black 300 lbs.	E. Nitrate of soda, 150 lbs.; muriate of potash, 200 lbs.	F. Dissolved bone-black, 300 lbs.; muriate of pot-ash, 200 lbs.	G. Nt. of soda, 150 lbs.; dis. bone-black, 300 lbs.; mu. of potash, 200 lbs.	H. Plaster, 200 lbs.	Farm manures.
	AVERAGE PRODUCE PER ACRE.	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*
Corn	27 experiments in 1878	24.6	30.4	33.5	33.3	39.1	39.6	42.9	48.6	28.9	45.9
	26 experiments in 1879	24.0	30.3	36.9	33.2	38.6	34.7	40.1	46.7	29.1	43.2
	20 experiments in 1880	32.1	35.2	43.2	37.1	46.8	40.3	47.5	48.1	39.8	46.6
	7 experiments in 1881	24.2	28.8	28.7	30.3	33.5	29.2	35.3	37.1	....	......
	80 experiments in 1878–'81	26.2	31.4	36.6	34.0	40.3	37.2	42.5	46.8	....	......
Potatoes	9 experiments in 1878	100.0	103.0	123.4	129.6	143.2	106.0	153.4	177.3	106.0	132.9
	9 experiments in 1879	58.2	76.4	90.7	86.5	96.3	84.7	123.0	143.6	69.3	131.6
	4 experiments in 1880	76.3	83.3	98.2	86.7	105.8	99.4	125.0	135.3	97.9	101.3
	3 experiments in 1881	28.2	44.2	43.7	39.7	54.4	41.9	59.5	87.7	....	......
	25 experiments in 1878–'81	72.5	83.2	98.0	96.4	109.6	89.6	130.8	147.7	....	......
	Average of the experiments in which farm manures were used:										
	Corn, 43 experiments:										
	Average produce	24.8	30.2	34.9	38.0	40.6	25.1	41.8	47.7	26.3	45.3
	Average increase	....	5.4	10.1	13.2	15.8	0.3	17.0	22.9	1.5	20.5
	Potatoes, 15 experiments:										
	Average produce	72.1	80.2	95.0	103.3	112.4	87.7	128.9	154.6	84.1	130.1
	Average increase	....	8.1	22.9	31.2	40.3	15.6	56.8	82.5	12.0	58.0
Sweet potatoes	5 experiments	71.2	133.9	102.3	164.3	124.5	195.2	164.9	214.2	(60.0)	272.7
Turnips	3 experiments	....	425.0	416.7	387.7	477.0	454.0	489.7	601.0	412.0	440.0
Sugar beets	1 experiment	795.0	1,013.0	1,174.0	851.0	1,116.0	988.0	1,091.0	1,119.0	961.0	......
Onions	1 experiment	290.0	530.0	510.0	680.0	620.0	500.0	650.0	610.0	400.0	390.0
Oats	4 experiments	21.6	25.0	36.1	22.6	47.7	38.1	30.2	41.5	....	......
Cotton	1 experiment	587.0	865.0	1,162.0	564.0	1,599.0	932.0	1,219.0	1,541.0	....	......
Clover	1 experiment	480.0	700.0	1,200.0	940.0	1,080.0	560.0	1,140.0	1,200.0	....	......
	AVERAGE INCREASE PER ACRE.										
Corn	80 experiments	....	5.2	10.4	7.8	14.1	11.0	16.3	20.6	....	......
Potatoes	25 experiments	....	9.3	25.5	23.9	37.1	17.1	58.3	75.2	....	......
Oats	4 experiments	....	3.4	14.5	1.0	26.1	16.5	8.6	19.9	....	......

Sweet potatoes	5 experiments	....	50.4	27.8	89.8	50.0	120.7	90.2	139.7	—14.5	198.2
Turnips	3 experiments	....	220.4	212.1	183.1	273.4	249.4	285.1	396.4	207.4	235.4
Sugar beets	1 experiment	....	218.0	379 0	56.0	321.0	193.0	294.0	323.0	164.0	......
Onions	1 experiment	....	240.0	220.0	390.0	330.0	210.0	360.0	320.0	110.0	100.0
Cotton	1 experiment	....	278.0	575.0	—23.0	1,012.0	345.0	632.0	954.0	....	......
Clover	1 experiment	....	220.0	720.0	460.0	600.0	80.0	660.0	720.0	....	......

TABLE XIII, PART I.—RECAPITULATION OF EXPERIMENT ON EFFECTS OF NITROGENOUS FERTILIZERS UPON CORN AND POTATOES.

[Increase in yield with mineral plus nitrogenous fertilizers over mineral fertilizers alone.]

"Mixed minerals" consist of 300 lbs. superphosphate, supplying 48 lbs. phosphoric acid, besides sulphuric acid and lime, and 150 lbs. muriate of potash, supplying 75 lbs. actual potash. "Nitrogen mixture" = Nitrogen of soda, sulphate of ammonia, and dried blood, in equal parts. The pecuniary results, gain or loss, from use of nitrogen are estimated by assuming a bushel of corn with its stalks to be worth 80 cents.

Yields per acre in bushels with no manure and with "mixed minerals."

Number of experiment.	CORN.									POTATOES.					
	No manure.				Mixed minerals.					No manure.			Mixed minerals.		
	0.	00.	000.	Average.	6.	6a.	6b.	16.	Average.	0	00.	Average.	6.	16.	Average.
A. 1878	20.3	25.5		22.9	39.0				39.0						
B. 1878	17.7			17.7	43.1				43.1						
D. 1878	11.3	7.0	10.1	9.5	70.3				70.3						
C. 1879	7.7	8.5		8.1	42.0			36.5	69.3	46.0	56.0	51.0	82.0	126.0	104.0
E. 1879	39.5	44.6	44.5	42.9				63.4	63.4						
F. 1879	8.2	14.1	10.5	10.9	50.2			45.9	48.1						
C. 1880	22.2	37.8		30.0	52.8			52.3	27.6	78.0	62.0	70.0	114.0	158.0	136.0
G. 1880	11.4	7.9		9.6	20.0			14.5	17.3						
H. 1880	46.8	46.9	61.8	51.8	71.0	78.2	71.4	74.3	73.7						
I. 1880	31.8	37.6	39.9	36.4	46.0	48.6	48.3	40.0	45.7						
K. 1880	22.5		25.0	23.8	22.5	30.0	27.5	33.3	28.3						
C. 1881	7.3	12.4		9.9	25.2			31.8	28.5	44.0	60.0	52.0	74.0	90.0	82.0
I. 1881										28.0	46.7	37.4	90.7	96.0	93.4
M. 1881	38.2	33.1		35.7	34.5	33.4	35.7	33.4	34.3	12.8	11.7	12.3	13.9	40.5	27.2
O. 1881	10.3			10.3	34.6	37.7	28.6		33.6						
L. 1881	12.5	13.8		13.2	13.8	16.3		20.6	16.9						
N. 1881	40.0	35.4		37.7	52.0	16.0	48.3	40.9	46.8						
P. 1881	16.3	16.5		16.4	28.2	30.1	29.0	39.7	31.8						
Q. 1881	44.6	31.6		38.1	58.9	56.7	51.1	57.2	56.0						
				23.6					43.0			44.5			88.5

Table XIII, Part II.—Pecuniary Results.

[Gain, +; Loss, —.]

EXPERIMENTS WITH CORN.

Cost of fertilizers:															
Whole	$14 25	$19 87½	$25 50	$9 37½	$18 75	$28 12½	$9 37½	$18 75	$28 12½	$13 87½	$19 12½	$24 37½	$18 75	$18 75	$19 32
Nitrogen	5 62½	11 25	16 87½	5 06¼	10 12½	15 18¾	5 06¼	10 12½	15 18¾	5 25	10 50	15 75	10 12½	10 12½	10 69½
Average of 3 experiments in 1878	+0 30	—6 21	—10 24	....	....	....	....	....	....	—0 37	—3 06	—7 83	—3 63	—5 65	—4 54
Average of 3 experiments in 1879	—3 47	—11 17	—18 80	....	....	....	....	....	....	—2 05	—12 26	—14 15	—3 41	—5 96	—5 65
Average of 5 experiments in 1880	+1 97	—0 37	+5 67	....	....	....	....	....	....	—2 29	—1 70	—1 02	—5 04	—2 12	—5 10
Average of 5 experiments in 1881	—4 01	—8 53	—12 47	—3 86	—5 56	—11 18	—3 03	—7 08	—11 34	—3 25	—8 18	—13 67	—16 04	—8 68	—12 13
Average of 5 experiments in 1878–'80	—1 03	—6 61	—11 75	—3 86	—5 56	—11 18	—3 03	—7 08	—11 34	—1 97	—6 26	—9 99	—7 32	—5 56	—6 85

EXPERIMENTS WITH POTATOES.

1 experiment in 1879	+3 38	—2 55	—7 87	....	....	....	....	....	....	+21 35	+2 70	—0 15	+9 08	+10 28	—5 89
1 experiment in 1880	+17 18	+41 55	+1 13	....	....	....	....	....	....	—17 25	—6 90	—14 65	+0 66	+0 08	—9 50
1 experiment in 1881	—11 30	—4 47	—16 15	—1 22	—12 38	—5 34	—17 92	—13 96	—16 44	—12 99	—10 14	—4 29	—1 10	—5 42	—4 13
1 experiment in 1879–'81	—10 82	—13 29	—9 73	—1 22	—12 38	—5 34	—17 92	—13 96	—16 44	—7 77	—4 02	—1 53	—2 38	—2 72	—2 71

TABLE XIII, PART III.—INCREASE OR DECREASE IN YIELD PER ACRE WITH NITROGEN.

[Estimated by subtracting yield with mineral fertilizers from yield with same plus nitrogenous fertilizers.*]

[Decrease indicated by —.]

EXPERIMENTS WITH CORN.

Number of plot.		7.	8.	9.							10.	11.	12.	13.	14.	15.
Nitrogen compounds added to mixed minerals.	Kinds.	Nitrate of soda.			Sulphate of ammonia.			Dried blood.			Nitrogen mixture.			Sulphate of ammonia.	Dried blood.	Peruvian guano.
	Pounds per acre.	150	300	450							150	300	450	225	450	
Nitrogen in above.	Pounds per acre.	24	48	72							24	48	72	48	48	48
	Number of experiment.	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*
	A. 1878	0.8	4.9	12.6							9.4	6.5	2.1	—3.1	5.3	9.1
	B. 1878	8.7	4.6	4.3							7.0	7.7	13.4	15.1	12.2	6.8
	D. 1878	13.7	9.4	8.1							1.8	13.6	14.3	11.9	—0.7	7.2
	C. 1879	3.7	4.8	0.2							4.7	5.2	—0.2	3.7	4.2	2.0
	E. 1879	—2.5	—2.0	—4.8							10.3		11.8	24.6	—0.5	8.2
	F. 1879	—9.4	—2.6	—2.7							—3.0	—9.6	—5.6	—3.1	11.9	8.7
	C. 1880	—2.8	1.2	—3.4							—5.4	—3.8	—1.7	—1.1	—0.3	—2.2
	G. 1880										—0.8	2.0	—1.1	4.9	8.7	—1.4
	H. 1880	—1.0	—4.3	—10.1							—0.7	0.2	2.4	—2.1	6.0	3.7
	I. 1880	11.5	15.1	11.4							9.9	17.9	19.8	9.0	10.2	11.5
	K. 1880	30.3	42.2	51.3							15.0	38.7	52.5	15.0	29.6	23.4
	C. 1881	3.6	—2.6	—6.4												
	L. 1881	9.5	27.9	42.9	12.2	26.2	32.0	8.2	13.2	20.0						
	M. 1881	2.8	—1.5	—0.3	2.7	3.9	—1.6	—1.6	—0.1							
	N. 1881	—2.9	—3.3	1.4	—4.3	—4.9	—7.2	—3.2	—1.5							
	O. 1881	—0.6	1.1	6.8	1.7	2.6	1.7	6.8	8.4	10.4						
	P. 1881	0.8	4.6	1.4	—2.3	1.3	3.5	8.7	1.8	—4.4						
	Q. 1881	—0.1	—2.2	—7.6	—0.9	5.0	—0.7	—1.7	—2.5	4.2						
	Ave. of exp't, 1881	1.9	3.4	5.5	1.5	5.7	5.0	2.2	2.9	4.8	2.5	2.9	2.6	—7.4	1.8	—1.8
	Ave. of 5 exp'ts, 1880	9.5	13.6	14.1							3.7	11.0	14.4	5.1	10.0	7.0
	Ave. of 3 exp'ts, 1879	2.7	0.1	—2.4							4.0	—2.2	2.0	8.4	5.2	6.3
	Ave. of 3 exp'ts, 1878	7.4	6.3	8.3							6.1	9.3	9.9	8.0	5.6	7.7
	Ave. of 3 exp'ts, 1878–'81	5.4	5.8	6.4	1.5	5.7	5.0	2.2	2.9	4.8	4.1	5.3	7.2	3.5	5.7	4.8

EXPERIMENTS WITH POTATOES.

C. 1879	15.0	23.0	15.0	....	....	....	....	....	....	46.0	22.0	26.0	32.0	34.0	8.0
C. 1880	38.0	88.0	30.0	....	....	....	....	....	....	—20.0	6.0	2.0	—18.0	0.0	—4.0
C. 1881	26.0	22.0	16.0	....	....	....	....	....	....	32.0	26.0	32.0	12.0	20.0	12.0
I. 1881	34.0	46.3	26.0	....	....	....	....	....	....	28.7	42.7	34.7	25.3	31.7	37.3
M. 1881	24.7	10.3	—38.4	6.4	37.5	34.2	—18.1	—6.4	—2.1	....	....	....	....	....	....
Ave. of exp't, 1881	28.2	26.2	1.2	6.4	37.5	34.2	—18.1	—6.4	—2.1	30.4	34.4	33.4	18.7	25.9	24.7
Ave. of exp'ts, 1879–'80	26.5	35.5	22.5	....	....	....	....	....	....	13.0	14.0	14.0	7.0	17.0	2.0
Ave. of exp'ts, 1879–'81	27.4	40.9	11.9	....	....	....	....	....	....	21.7	24.2	23.7	12.9	21.4	13.3

* In making these calculations for Experiments C, E, F, and G, the yields on Plots 7, 8, and 9, Group I, were compared with that of Mixed Minerals No. 6; the yields of 13, 14, and 15, Group III, with Mixed Minerals No. 16; and those of Plots 10, 11, and 12, Group II, with the average of Nos. 6 and 16. But in Experiments H, I, and K, each group had a "mixed minerals" plot on each side; accordingly the yields of the first plots of each group were compared with that on the adjoining "mixed minerals" plot, and the middle one with the average of the two "mixed minerals" plots.

DETAILS OF SPECIAL NITROGEN EXPERIMENTS.

OBSERVATIONS REGARDING SOIL, WEATHER, CULTURE, CHARACTER OF PRODUCE, AND OTHER DETAILS.

As shown by the reports of individual experiments, of which examples have been given elsewhere, more or less extensive observations have been made and recorded concerning the circumstances and conditions of the experiments and the character of the results. A faithful statement of these observations, following as nearly as possible the language of the experimenters, will be valuable: to the experimenters, to show what their fellow-workers have done, and how; to other farmers who, in applying the results to their practice, will find profit in comparing the experimenters' circumstances with their own; to help, in general, to juster criticizing and valuation of the experiments, interpretation of the results, and improvement of plans and methods; and, finally, and most of all, to show what good work farmers can do in applying the methods of scientific investigation to the discovery of the principles on which their practice should be based.

The following details of the reports have been transcribed under my direction, with only such alterations as accuracy allows and omissions as the permitted space demands. Only the details of the nitrogen experiments are given here, however. Those of the general experiments, though most interesting and valuable, are necessarily omitted. Some of the principal facts, however, are included in Tables IV–X.

NITROGEN EXPERIMENTS.

A. 1878. PROF. J. R. FARRINGTON, Maine State College of Agriculture and Mechanic Arts, Orono, Me.—Experiment with *Corn.*

SOIL.—*Situation*, nearly level, but with a slight swell running across the middle of the field, draining the surface water off each way in the direction of the length of the rows. KIND, heavy clay, *dry or wet*, moist, not underdrained. *Texture*, compact. PREVIOUS TREATMENT AND YIELD.—In meadow (mowing) for ten years. In 1873–'74 plots running at right angles to and nearly across the plots of the present experiment received a manuring of mineral and nitrogenous fertilizers. If any effect from those fertilizers remained it would be felt alike by all of the present plots. TILLAGE, &C.—The land was plowed six inches deep ten days before it was planted; was prepared for planting by thoroughly pulverizing with Randall's harrow; measured rows marked with a marker drawn by hand. Fertilizers mixed with sawdust, carefully distributed, worked into the soil, and seed dropped and covered with a hoe. OTHER REMARKS.—The soil of the field has a remarkable uniformity of appearance.

B. 1878. W. I. BARTHOLOMEW, Pomfret (P. O. address, Putnam), Conn.—Experiment with *Corn.*

SOIL.—*Situation*, summit of hill. *Kind*, black, clayey loam, yellow below; at 1½ or 2 feet becomes a stony, compact clay. *Texture*, loose surface if not trodden when wet. *Dry or wet*, variable with the season. *Depth of surface soil*, 6 or 8 inches. *Subsoil*, hard and compact. PREVIOUS TREATMENT AND YIELD.—Never received much manure previous to 1875. In grass in 1875–'77, crop about one ton. FERTILIZERS, HOW APPLIED.—Scattered in and around the hills before dropping the corn. TILLAGE.—Hoed twice, and corn thinned to four stalks in hill at second hoeing. A small part of Nos. 10 and 11 were replanted, and corn did not get so large a growth in those plots. WEATHER.—Favorable; corn came up well, and stood remarkably well through the season. OTHER REMARKS.—After drying one month the ears showed a shrinkage of about 5 per cent. in weight. 70 pounds of ears as harvested yielded, after drying one month, 55¾ pounds of shelled corn. One bushel dry shelled corn weighed $60\frac{5}{16}$ pounds,

PLOTS.—Size, $\frac{1}{10}$ acre. *Rows*, 3½ feet apart. *Kind of corn*, white cap corn. *Planted*, May 16—20. *Harvested*, September 30-October 10.

C. 1879, 1880, and 1881. Also by Mr. BARTHOLEMEW.—Experiments with *Corn* and *Potatoes*, side by side, as per description of experiment of 1878.

The experiment was on a part of the same field as that of 1878, and the other details were similar.

C. 1879. WEATHER.—In 1879, cold, wet, and unfavorable to corn throughout; better for potatoes: except in spring potatoes came up slowly. Severe storms in July and August. Frost killed corn (September 25) before maturity. Potatoes were planted, like the corn, in hills 3½ by 3½ feet, which gives not more than half the hills usually made per acre for this crop, but were so planted for uniformity, and to allow cultivating both ways. No doubt there would have been nearly double the number of bushels if they had been planted as thick as usual. The hills on the best plots were so full of fine, smooth potatoes as to excite great approbation among those who saw them, and not as much worm-eaten as was common here this season.

C. 1880. WEATHER.—Good for corn, but too hot and dry for potatoes, although my crop was very good when compared with most of my neighbors. Fertilizers applied in the drill. These experiments with potatoes are perhaps the most unsatisfactory to me of any that I have reported. In some of the plots the seed appeared to be injured by the fertilizers and were replanted, but this was of little result. Accidents prevented uniformity in hoeing, which appeared to affect the crop; and also trusting slightly to others in harvesting makes some of the figures a little uncertain.

C. 1881. WEATHER.—*May*, latter part of month very warm. *June*, cold and wet. Severe cold storm before crops came up. *July*, frequent and severe showers. Hard hailstorm July 4th. *August*, cloudy. Unfavorable for both corn and potatoes in this section. The crops of both were light. FERTILIZERS APPLIED as in former experiments, but a severe storm coming on soon after the corn and potatoes came up, dissolved the fertilizers and appeared to injure the young plants slightly, especially where the quantity was largest. *Planting and tillage* as heretofore. OTHER REMARKS.—A severe hailstorm July 4th broke down and battered the young plants, both of corn and potatoes so badly that I almost despaired of a crop worth reporting, and was advised to plow it up and sow buckwheat instead, but the potatoes finally made a fair growth, although the yield was too small. The corn was perhaps the most injured, and, as the season was bad, was very poor. Although the crops were small in consequence of the hail, &c., perhaps the relative effects of the fertilizers were as manifest as in a good season. The same marked difference existed that has characterized the use of different fertilizers with me from the beginning of my experimenting, several years ago. The first year's story is repeated each successive year, only as modified by the seasons. Most likely the storm about the 1st of June, which completely saturated the ground, gave some of the plots which were lightly fertilized, or not at all, the benefit of fertilizers of adjacent plots, especially the 00 plot. The ground descends from the larger numbered plots toward the smaller numbered ones, and consequently the fertilizers tended in a flood in that direction.

D. 1878. CHESTER SAYE, Middletown, Conn.—Experiment with *Corn*.

SOIL.—*Situation*, upland, sloping to the east. *Kind*, loam, some cobble-stones *Texture*, loose, not drained, compact after rains. *Depth of surface-soil*, about 6 inches. *Subsoil*, yellow, with cobble-stones, hard in dry weather. *Other remarks*, the land "has been faithfully neglected." PREVIOUS TREATMENT AND YIELD.—No manure put on for three years previous to 1875. No manure in 1875–'77, crop, 1½, 1 and ⅗ tons of hay per acre. WEATHER.—*April*, rain, 5th, 10th, 11th, 21st, 23d, 25th, 28th, 29th. *May* rain, 5th, 9th, 20th, 21st, 25th, 30th, 31st. *June*, rain, 3d, 10th, 11th, 12th, 13th, 17th, 18th 22d, 24th, 27th. *July*, rain, 4th, 9th, 10th, 12th, 21st, 27th, 30th. *August*, rain, 1st, 2d

4th, 6th, 9th, 16th, 20th, 21st, 25th. FERTILIZERS, HOW APPLIED.—Broadcast and cultivated in. TILLAGE.—Cultivated both ways twice and hoed. OTHER REMARKS.—The birds pulled the corn badly, and although it was replanted there were some missing hills. Many hills in each plot had a less number of stalks than was intended. The number of hills in each plot containing one or more stalks was counted, and the yield per acre estimated as if the missing hills had yielded corn equal to those hills that grew. PLOTS.—454 feet × 7½ feet = $12\frac{7}{12}$ square rods. (Fertilizers applied at rate of one-tenth acre for each bag.) *Rows*, 3¾ feet apart. *Hills*, 3¾ feet apart. *Planted*, May 29. *Harvested*, October 25 and 26. *Pounds allowed for a bushel of produce*, 70 of good ears, 140 of poor ears.

E. 1879. Experiment with corn; also by Mr. SAYE, but on another field of the same farm.

SOIL.—Upland northern slope, gravelly loam, thin turf, compact, dry. Depth of surface soil 5 inches. *Subsoil*, yellow and heavy. PREVIOUS TREATMENT AND YIELD.—No manure, one-half ton hay in 1876 and '77; no manure, three-fourths ton hay '78. FERTILIZERS, HOW APPLIED.—Sowed broadcast on each row, except unmanured rows, which were 3 feet 9 inches wide. Plots, 440 feet by 3 feet 9 inches = $6\frac{1}{10}$ square rods. *Crop*, corn. *Rows*, 3 feet 9 inches apart. *Hills*, 3 feet 9 inches. *Planted*, May 28. *Harvested*, first week in November, 70 pounds in ear per bushel. Tillage. OTHER REMARKS.—This report includes only three unmanured rows. For 20 rows each alternate row was without manure, so that the first 10 rows with manure had 10 rows without manure between them, and had I saved rows enough for the whole 16 rows of the experiment, I should have separated every row where manure was put by or with a row where no manure was put.

F. 1879. JOHN B. MEAD, Randolph, Orange County, Vermont.—Experiment with *Corn*.

SOIL.—Base of hill southeast slope. *Kind*, dark loam, with some clay, light when dry. *Dry or wet*, variable with the season, dry enough for corn. *Depth*, 4–8 inches. *Subsoil*, somewhat hard and compact. PREVIOUS TREATMENT AND YIELD.—Run out meadow with — ton to half a ton of hay per acre. Plowed in 1878 and sowed to oats with no manure; yield, 25 bushels. WEATHER.—Cold and backward in spring and early summer; worst season for corn in this section for 20 years. SIZE OF PLOTS.—Eight square rods. *Planted*. May 26. *Harvested*, October 8. FERTILIZERS APPLIED broadcast by hand, being careful that each plot received its own and no more. PLANTING AND TILLAGE.—Thoroughly worked with harrow before application of fertilizers; seed planted with horse planter in hills about 2 feet apart. Cultivated twice and kept free from weeds by hand-hoeing. OTHER REMARKS.—The labor was less than usual in corn raising. The season being unfavorable, the crop was small, but the experiment has taught me much that is valuable to me, and if it will repeat itself, as I think it will repeat itself, it will be worth thousands of dollars upon my farm.

G. 1880. PROF. W. H. JORDAN, Maine Agricultural and Mechanical College, Orono, Me.—Experiment with *Corn*.

SOIL.—Upland quite level. *Kind*, clayey loam, with a strip across somewhat lighter, with small stones very similar to A. 1878. *Dry or wet*, medium. PREVIOUS TREATMENT.—Pasture. WEATHER.—A very dry season, indeed, until about the last of August. The drought injured the crop very much. FERTILIZERS, HOW APPLIED.—In hill, with thorough mixing with soil. TILLAGE.—The land was plowed in the spring just before planting and pulverized with a Randall harrow. The land had also been plowed the fall previous. Thorough tillage was kept up during growing season.

H. 1880. EDWARD HICKS, Old Westbury, Queens County, New York.—Experiment with *Corn.*

SOIL.—Level, sandy loam, dark color, light and loose. *Dry or wet.* Dry. *Depth of surface soil,* 6–8 inches. *Subsoil,* yellow loam. WEATHER.—Dry, though very favorable; crop throughout the island unusually heavy. The drought had no perceptible effect upon the growth of the corn. FERTILIZERS, HOW APPLIED.—The ground was laced out 3 feet 9 inches apart, with a light lace and the fertilizer for each plot was put in a pail and the pail filled with dry earth and thoroughly mixed with the fertilizer; this gave an even quantity to apply to each plot on the lace marks. The corn planter opening a furrow through the lace marks, stirred the fertilizer and soil together. TILLAGE.—The corn ground was smoothed with a plank drag and harrowed twice after the corn was up, then cultivated twice, leaving the ground perfectly level. It was hoed and thinned out at the same time, leaving the plants 10 to 12 inches apart. OTHER REMARKS.—The corn was not husked till November 24–30, and as some of the stalks were blown down and wet we did not weigh the stalks. The stalks appeared to be very uniform throughout the whole of the plots. Since reading your remarks in the American Agriculturist about the length of plant roots, I think that a vacant plot should be between every fertilized plot. My unmanured plots were too narrow. I do not think they would have yielded near as well had they been, say, four rows wide, and to take account of only the two middle rows. The second and third plot got mixed in cutting up the corn on one end of the plots, and the figures for them are not as exact, having to estimate from the other end of the two plots. No width was allowed except width of the rows 3 feet 9 inches.

P. 1881. HICKS, as above.—Experiment with *Corn.*

SOIL.—Dead level. *Kind,* sandy loam, light. *Dry or wet,* dry. *Depth of surface soil,* 7-9 inches. *Subsoil,* yellow loam, 4-8 inches, then gravel. PREVIOUS TREATMENT AND YIELD.—Corn, succeeded by potatoes and oats; then winter wheat and rye, seeded with timothy and clover; mowed three years, then pasture one or two years. WEATHER.—Planted 18th to 20th of May; ground in good, warm condition. *June,* favorable; little too cool. *July,* dry. *August,* very dry. Very unfavorable the last half of the growth of the crop. FERTILIZERS, HOW APPLIED.—Broadcast on six rows, so that the outside rows did not have any fertilizer on the outside of the row. Each bag was mixed thoroughly with sifted, damp earth, to bring the quantity of each bag to two large parts full. A pailful was applied to each three rows; the damp earth helped to prevent the wind from blowing the dry fertilizers. TILLAGE.—Albany corn, planted with a weighted wheel to follow and press the earth firmly upon the seed. Used a smoothing harrow as soon as the corn was six inches high. Cultivated, then hoed and thinned out to one plant to 10 to 12 inches. Worked out the corn twice with riding Disc harrow; this hilled up the corn perhaps too much. OTHER REMARKS.—By referring to diagram of unmanured plots you will observe that the north end of the plots yield very much more than the others. You will also observe that plot 6*c*, mixed minerals, is much larger in yield than the other plots, 6, 6*a*, 6*b*, mixed minerals, which are quite uniform. I attribute it to either having had potatoes planted on the north side of the field adjoining the fence the last time it had potatoes and oats, about seven years ago, or to snow-banks lying there, or both; it is where we had potatoes, I have no doubt, as they were manured very heavily. Now this makes a want of uniformity in the soil, and plots Nos. 1 and 6 are not a correct yield from the fertilizer applied. Perhaps plots Nos. 2 and 15 are also a little affected by it. I take the average of unmanured plots on the east side for No. 0, and on the west side for No. 00.

I. 1880. CHARLES FAIRCHILD, Middletown, Conn.—Experiment with *Corn.*

SOIL.—Upland level, sandy loam, light, and loose. *Dry or wet,* dry, decidedly. *Depth of surface soil,* about 6 inches. *Subsoil,* sandy and gravelly. PREVIOUS TREAT-

MENT AND YIELD.—Previous to 1877 the field was an old pasture, thoroughly run out and already infested with bushes; it had not been plowed for twenty years or more. WEATHER.—*May*, very dry; severe drouth. *June*, very dry, but some showers. *July*, considerable wet weather early in the month. *August*, fine growing weather; on the whole very favorable for corn. FERTILIZERS, HOW APPLIED.—Sowed broadcast and harrowed in. Between each two plots was left an unmanured strip two feet wide; that is, the fertilizers were spread so as to cover 8½ feet of the 10½ feet of the width of the plot, thus leaving a foot on each side of each plot, or a strip two feet wide between each two plots unmanured. TILLAGE.—Planted 4 kernels in each hill; hills 3½ feet apart each way; cultivated both ways four times; not hand-hoed. OTHER REMARKS.—Neither nitrogen nor potash alone seemed to help much, but with other materials each increased the yield. In other cases muriate of potash alone has proved very efficient.

I. 1881.—Experiment with *Corn*.

SOIL.—Upland, level sandy loam, light. *Dry or wet*, dry. *Depth of surface soil*, 5-6 inches. *Subsoil*, sandy and gravelly. PREVIOUS TREATMENT AND YIELD. Pasture. WEATHER.—Favorable. FERTILIZERS, HOW APPLIED.—Broadcast.

I. 1881.—Experiment with potatoes.

SOIL.—Similar to I, 1881, with corn. WEATHER.—*May*, warm. *June*, cold and wet. *July*, warm and dry. *August*, warm and dry. FERTILIZERS, HOW APPLIED.—Broadcast. TILLAGE.—Planted in drills 3½ feet apart, 2 feet in row. The potatoes were cut in small pieces, with two eyes in a piece, and one piece in a place. Hoed by hand once, cultivated with horse hoe three times.

K. 1880. WILLIAM C. NEWTON, Durham, Conn.—Experiment with *Corn*.

SOIL.—Upland slope to northeast, dark loam, few stones. *Dry or wet*, moist. *Depth of surface soil*, 5–6 inch. *Subsoil*, yellow loam, some stones. PREVIOUS TREATMENT AND YIELD.—1876, corn with a hundred pounds guano per acre, yielded about 150 bushels of ears per acre. 1875, corn, 1 ton of fish scrap per acre yielded about 125 bushels ears per acre. 1874. 1 ton of fish scrap per acre yielded about 110 bushels per acre. I think in 1876 there were some German potash salts applied, do not know the quantity. WEATHER.—Season favorable for corn. FERTILIZERS, HOW APPLIED.—Special nitrogen set half size, applied broadcast. TILLAGE.—Hand hoed once, cultivated twice, which kept the ground free from weeds. Plowed between the different plots in order to cut the roots and prevent them feeding on the adjoining plot.

L. 1881. Also by Mr. NEWTON. Adjoining portion of the same field as the experiment of 1880.

M. 1881. Prof. C. L. INGERSOLL, La Fayette, Ind.—Experiment with *Corn*.

SOIL.—First level or bluff 100 feet above level of Wabash River; black soil, similar to prairies, but with less organic matter; finely divided and sticky when wet; bakes when dry. *Dry or wet*, naturally dry; well drained. *Depth of surface soil* 8 to 24 inches. *Subsoil*, gravel 30 to 90 feet deep. Best suited for corn and wheat. Corn varies from 30 to 40 bushels per acre; wheat 18 to 30 per acre. PREVIOUS TREATMENT AND YIELD.—Treatment not known previous to 1878; supposed in grass, either meadow or pasture, for four years at least. 1878, pasture. 1879, pasture. 1880, corn; 38.7 bushels per acre. WEATHER.—*April*, cold first half, warm second half. Rather dry; 2.25 in. rain-fall. Frost to the 17th. *May*, warm except first week; rain-fall, 3.82 inches. Drought from May 15 to June 5. *June*, warm and wet from 5 to 20. Rain-fall, 7.16 inches. No

rain except twice from July 22 to September 2. Rain-fall 2.5 inches, in 10 days; hot and dry. Temperature 103° for two days. *August*, very hot and dry: temperature 100° or over for 10 days. Highest temperature, 107°. Rain-fall, 0.47 inch. Very unfavorable season for the crop. FERTILIZERS, HOW APPLIED.—Applied by hand after mixing with about twice its bulk of earth. Distributed a foot on either side of the row. TILLAGE AND PLANTING. Planted by hand in hills 4 feet 2 inches apart each way. In rows for cultivation in two directions. Tillage by horse. OTHER REMARKS.—Land plowed May 9: harrowed once, May 11, with smoothing harrow. Planted May 12, 6 and 7 grains in a hill. Fertilizers applied May 14; cultivated five times. No unmanured strips between plots, except in Nos. 1 and 20, 0 and 00 of corn plan. Scattering weeds hoed out July 9; corn cut *October* 1 and 3. Husked *October* 8 and weighed *October* 15.

M. 1881. *Potatoes*. Similar to corn, 1881, in respect to soil, weather, and application of fertilizers. Planted by hand in hills 1 foot 4 inches apart in rows for cultivation in one direction. *Tillage* by horse and by hand. Potatoes cut in about six pieces and two dropped in a place. Rows 33 inches apart. Cultivation only north and south. OTHER REMARKS.—Land plowed April 22; harrowed once with smoothing harrow. Planted April 23; cultivated five times. Hoed *June* 11 and *May* 18. No unmanured plots except 0 and 00. Five feet width between these and the manured plots. Potatoes dug and weighed September 24. Unfortunately part of our seed was mixed, and hence the results are not as accurate as we would wish.

N. 1881. C. E. THORNE, farm manager, Ohio State University, Columbus, Ohio.—Experiment with *Corn*.

SOIL.—Level upland, clayey loam, dark, medium amount of vegetable matter. "Drift" formation from Huron shale moderately compact, thoroughly drained in *April* and *May*. *Dry or wet*, wet before drainage. *Depth of surface soil*, owing to the formation the division between the surface soil and subsoil is not distinctly marked. The plow has been lowered to 12 inches without increase of crop. *Subsoil*, about 18 inches below surface of bowlder clay; very retentive. PREVIOUS TREATMENT AND YIELD.—1876 sowed to grass, but it failed to take; 1877 corn. WEATHER.—*April*, cold and wet; during the first half a heavy snow covered the ground; closed dry. *May* dry. *June* dry; one good rain about the 10th. *July* dry; light rains latter part of month. *August* dry. Season so dry as to cause a loss of 50 per cent. in yield. FERTILIZERS, HOW APPLIED.—The fertilizers were spread by hand in strips 2½ to 3 feet wide, having the corn row as the center of the strip. The rows were of such length that three rows occupied $\frac{1}{10}$ acre of land. The stable manure was spread in a continuous strip, occupying the whole width of the plot. TILLAGE.—The corn was planted (east and west) with a two-horse corn-planter, on the 26th of May. It was cultivated four times during the season with a two-horse cultivator.

O. 1881. J. W. PIERCE, West Millbury, Mass.—Experiment with *Corn*.

SOIL.—Upland, nearly level, except southwest corner, which is on hill-side; clay and gravelly loam: color light, with yellow subsoil, light and mellow in texture. *Dry or wet*, dry, but does not suffer from drought. *Depth of surface soil*, from 6 to 7 inches. *Subsoil*, gravelly, with some clay. PREVIOUS TREATMENT AND YIELD.—Most of it manured and planted with corn in 1875; oats, without manure, in 1876; clover, without manure, in 1877. WEATHER.—*April*, wet. *May*, first half warm, last half wet and cold. *June*, wet and cold. *July* dry, but cloudy and cold. *August*, first part cold, last part warm; and *September*, warm and dry: on the whole cold and unfavorable for corn. FERTILIZERS, HOW APPLIED.—Sown broadcast and harrowed in with wheel harrow. The small messes were mixed with enough damp sawdust to make the bulk of each bag about the same, and sown thicker in center of plots than at sides. In planting the ground was marked both ways $3\frac{3}{10}$ feet apart, or 25 hills to the square rod.

TILLAGE. It was cultivated three times each way; hoed once, and horse hoed both ways when just tasseling, August 8. OTHER REMARKS.—These plots have a southwest aspect.

Q. 1881. SAMUEL JOHNSON, Agricultural College, Lansing, Mich.—Experiment with *Corn.*

SOIL.—Level upland, sandy loam, except about ⅛ of each plot at the east end, which is clayey loam. *Texture,* light and loose; drained. *Dry or wet,* dry, but withstands drought well. *Depth of surface soil,* about 8 inches. *Subsoil,* mostly sandy or gravelly; clay at east end of plots. PREVIOUS TREATMENT AND YIELD.—In 1874 corn; 1875 roots, with good dressing of barn-yard manure; 1876 oats; 1876–'77 wheat and seeded to clover. WEATHER.—*April,* cold and wet. *May,* favorable. *June,* rains on 8th and 12th; 15th to 23d, cold, with some showers; 27th rain; too cold during month for corn. *July,* rain on 7th; latter part too cold; entirely too dry. *August,* rain 5th and 18th; warm, but too dry. Unfavorable on the whole. FERTILIZERS, HOW APPLIED.—By hand, then thoroughly harrowed into the soil with a Thomas smoothing harrow before planting. Each plot consisted of a single row, which was unmanured 10 feet on either side, making the manured strip 4 feet wide. An unmanured strip 4 feet wide was left between each plot of corn. The corn was planted in hills 4 feet apart in the row; the rows were 8 feet apart; that is, every other row was left vacant. TILLAGE.—The crop was cultivated five times. A few weeds were pulled late in the season. OTHER REMARKS.—The shelled corn is estimated from average samples of the good corn, which were thoroughly dried and shelled January 9, 1882. The shelled corn averaged nearly 71 per cent. of the fresh corn in the ear, owing to wet weather previous to husking; neither corn nor fodder was very dry when husked.

S. 1881. Prof. W. C. STUBBS, Auburn, Lee County, Ala.—Experiment with *Cotton.*

SOIL.—Level upland, sandy, with small quantity of vegetable matter; light, well drained. *Dry or wet,* very dry. *Depth of surface,* 4 to 6 inches. *Subsoil,* reddish yellow clay. PREVIOUS TREATMENT AND YIELD.—It had been pastured. Bermuda grass had grown up here and there in patches, but was nearly all removed by hand, and hoed before experiment. WEATHER.—*May,* planted; seasonable. *June,* seasonable. *July,* long drought, but on account of late planting did but little damage. *August,* showery and seasonable. On whole, rather unfavorable season. FERTILIZERS, HOW APPLIED.—In drill, and bedded on them. Three rows 3 feet wide to each experiment. Each parcel of fertilizer weighed into three equal parts. Mixed evenly with dry earth, and applied as carefully as a skilled hand could do it. TILLAGE AND PLANTING.—Planted with ordinary cotton-planter. Chopped to a stand, and cultivated with cultivator sweep and hiller. OTHER REMARKS.—Only a fair stand was obtained. Cotton planted too late, on account of detention of fertilizers "in transitu" from New York.

S. 1881. J. M. MANNING, Raynham, Taunton, Bristol County, Mass.—Experiment with *Clover.*

SOIL.—Upland, with gentle slope to the east, southeast, and northeast; sandy loam; some gravel and small stones on south side, loose; lower corner northeast more compact. *Dry or wet,* medium. *Depth of surface,* 6 or 7 inches. *Subsoil,* yellow sand. PREVIOUS TREATMENT AND YIELD.—A small crop of grass taken off each year for several years, and no manure applied. WEATHER.—*April,* wet. *May,* wet; third week very rainy. *June,* wet; rain on the 2d, 3d, 7th, 8th, 10th, 19th, 26th, and 30th. On the 28th three heavy showers. *July,* light shower on the 2d, 4th, and 8th; heavy shower on the 21st; last week cloudy and rainy. *August,* dry; last part hot. The first part of the season, May and June, very hot, which occasioned delay in seeding. July fa-

vorable; August and first half of September too dry. FERTILIZERS, HOW APPLIED.—Bushed in the seed, driving lengthwise of the plots, and rolled the ground. Mowed the grass with a machine September 16, driving directly across the plots, north and south. Raked each plot separately, by setting up five stakes in a line between two plots, and moving each stake three paces or 9 feet as we came to it in raking. I. Spread the fertilizer uniformly, leaving a strip three-fourths of a foot wide between each plot unmanured; harrowed the ground lengthwise of the plots. These extended east and west, at right angles with those in the experiments of the previous years. III. The very heavy showers on the 28th of June, three days after sowing the seed, washed some of it away, and into hollow places, and probably some of the fertilizer with it. OTHER DETAILS.—At intervals on plot No. 5, about one-third of its area in all, nothing came up, scarcely a weed. The ground was nearly level, yet possibly the bush dragged the seed into the hollow places. I have added to the actual weight of hay on this plot one-half its weight, to make up for the vacant places. The clover came up quite uniformly on the other plots, though it did not make a large growth, on account of the late sowing and dry weather in August. Weeds were thrown out. Considerable fine grass came up of its own accord among the clover. September 21 carted the hay into the barn and weighed it. The hay was dry and of good quality for producing milk.

DEPARTMENT OF AGRICULTURE, COMMISSIONER'S OFFICE.

The following paper, prepared for this country and read before the American Association for the Advancement of Science, in August, 1882, is considered an important addition to the views of Professor Atwater contained in this volume.

GEO. B. LORING,
Commissioner.

DETERMINATIONS OF NITROGEN IN THE SOILS OF SOME OF THE EXPERIMENTAL FIELDS AT ROTHAMSTED, AND THE BEARING OF THE RESULTS ON THE QUESTION OF THE SOURCES OF THE NITROGEN OF OUR CROPS.

BY SIR JOHN BENNETT LAWES, BART. LL. D., F. R. S., F. C. S., AND JOSEPH HENRY GILBERT, PH. D., F. R. S., F. C. S., F. L. S.

It is just about a century since the question of the sources of the nitrogen of vegetation became a subject of experimental inquiry, and also of conflicting opinion. It is nearly half a century since Boussingault was led by a study of the chemistry of agricultural production to see the importance of determining the sources of the nitrogen periodically available to vegetation over a given area of land. Somewhat later, the Rothamsted experiments, now in their fortieth year, were commenced, and in their progress many facts have been elicited bearing upon the same subject. Still, almost from the date of Boussingault's first investigations, the question has been one of controversy, and at the present time very conflicting views are entertained respecting it.

For ourselves, we have pointed out how entirely inadequate is the amount of combined nitrogen coming down in the measurable aqueous deposits from the atmosphere to supply the nitrogen of the vegetation of a given area. Other possible supplies of combined nitrogen from the atmosphere have also been considered and pronounced inadequate. Again, the question whether or not plants assimilate the free or uncombined nitrogen of the atmosphere has been the subject of laborious experimental inquiry, and also of critical discussion, at Rothamsted. Finally, the question whether the stores of the soil itself are an important source of the nitrogen of our crops has frequently been considered.

It may at the outset be frankly admitted that so long as the facts of production alone are studied, without knowledge of, or reference to, the changes in the stock of the nitrogen in the soil, it would seem essential to assume that a large proportion of the nitrogen of crops growing without any direct supply of it by manure must be derived, in some way or other, from atmospheric sources. The assumption which is most

in favor with some prominent writers is, that whilst some plants derive most or all of their nitrogen from the stores of the soil itself, or from manure applied to it, others derive a large proportion from the free nitrogen of the atmosphere. We, on the other hand, whilst freely admitting that the facts of production are not conclusively explained thereby, have maintained that such collateral evidence as the determinations of nitrogen in our soils afford, is in favor of the supposition that the soil may be the source of the otherwise unexplained supply of nitrogen. This latter conclusion we have frequently stated in general terms, but we have not hitherto published the numerical results upon which it is based. Fairly enough, it has been objected that such an important conclusion cannot be accepted without the numerical evidence to support it. Further, erroneously interpreting our statements, calculations have been made to show that it is quite beyond the reach of present methods of determination of nitrogen in soils to afford results justifying the conclusions we have drawn. Since this subject of the sources of the nitrogen of our crops has been much discussed in America, it has been thought that it would not be inappropriate to answer the challenge by bringing forward some of the numerical evidence we have accumulated before this meeting of the American Association for the Advancement of Science, and to do this is the object of the present communication.

Before calling attention to the special results in question, it will be necessary, however, to convey a clear idea of the problem to be solved, by recapitulating some of the important facts which have been established as to the amount of nitrogen yielded over a given area by different crops. In his original inquiries Boussingault estimated the amounts of nitrogen supplied by manure and removed in the crops in ordinary agricultural practice. This mode of estimate is also the one generally adopted by others, and we have ourselves not neglected it. But it is obvious that the results of experiments in which different crops have been grown for very many years in succession on the same land, both separately and in actual course of rotation, and both without nitrogenous manure and with known quantities of such manure, must afford very important data as to the amounts of nitrogen available to vegetation, from soil and atmosphere, over a given area. The Rothamsted field experiments are pre-eminently adapted to provide such data. Thus, wheat has now been grown for thirty-nine years in succession on the same land; barley for thirty-one years; wheat in alternation with fallow thirty-one years; beans for nearly thirty years; clover for many years; turnips, sugar-beet, or mangels nearly forty years: whilst experiments on the mixed herbage of grass-land have been continued for twenty-seven years, and on an actual course of rotation for thirty-five years. We have, from time to time, published what we may call the nitrogen statistics of the crops so grown; and we have compared these facts of production with what is known of the sources of nitrogen available to the crops.

YIELD OF NITROGEN IN DIFFERENT CROPS.

The following table (I) shows the yield of nitrogen per acre per annum in wheat, barley, root crops, beans, clover, and in ordinary rotation, in each case without any nitrogenous manure. It will be observed that only in the case of the root crops is the record brought down to a later date than 1875. Independently of the fact that the requisite nitrogen determinations are not yet completed for the subsequent period, it has been decided that owing to the number of very exceptionally unfavorable seasons for corn crops which have occurred since 1875, it would be fallacious to bring the results for those crops in the later seasons as illustrating the falling off of yield due to soil exhaustion.

TABLE I.—*Yield of nitrogen per acre, per annum, in various crops at Rothamsted, without nitrogenous manure.*

Crop, &c.	Condition of manuring, &c.	Duration of experiment.	Average nitrogen per acre per annum.
			Pounds.
Wheat	Unmanured	8 years, 1844–'51	25.2
		12 years, 1852–'63	22.6
		12 years, 1864–'75	15.9
		24 years, 1852–'75	19.3
		32 years, 1844–'75	20.7
	Complex mineral manure	12 years, 1852–'63	27.0
		12 years, 1864–'75	17.2
		24 years, 1852–'75	22.1
Barley	Unmanured	12 years, 1852–'63	22.0
		12 years, 1864–'75	14.6
		24 years, 1852–'75	18.3
	Complex mineral manure	12 years, 1852–'63	26.0
		12 years, 1864–'75	18.8
		24 years, 1852–'75	22.4
Root crops	Complex mineral manure: Turnips	8 years, 1845–'52	42.0
	(Barley)	3 years, 1853–'55	(24.3)
	Turnips	15 years, 1856–'70[1]	18.5
	Sugar beet	5 years, 1871–'75	13.1
	Mangles	5 years, 1876–'80	15.5
	Total	36 years, 1845–'80	25.2
Beans	Unmanured	12 years, 1847–'58	48.1
		12 years, 1859–'70[2]	14.6
		24 years, 1847–'70	31.3
	Complex mineral manure	12 years, 1847–'58	61.5
		12 years, 1859–'70[2]	29.5
		24 years, 1847–'70	45.5
Clover	Unmanured	22 years, 1849–'70[3]	30.5
	Complex mineral manure	22 years, 1849–'70[3]	39.8
Barley	Unmanured	1 year, 1873	37.3
Clover		1 year, 1873	151.3
Barley	Unmanured: After barley	1 year, 1874	39.1
	After clover	1 year, 1874	69.4
	Barley after clover more than after barley		30.3
Rotation 7 courses	1. Turnips; 2. Barley; 3. Clover or beans; 4. Wheat — Unmanured	28 years, 1848–'75	36.8
	Superphosphate	28 years, 1847–'75	45.2

(1) Thirteen years' crop, two years failed. (2) Nine years' beans, one year wheat, two years' fallow. (3) 6 years' clover, 1 year wheat, 3 years' barley, 12 years' fallow.

YIELD OF NITROGEN IN WHEAT AND BARLEY.

The first series of results relate to the yield of nitrogen in wheat grown thirty-two years in succession on the land without manure. It is seen that over the first eight years the yield was 25.2 pounds of

nitrogen per acre per annum, over the next twelve years 22.6 pounds, and over the last twelve of the 32 years only 15.9. There has thus been a considerable reduction in the annual yield of nitrogen over each succeeding period; and for the third period of twelve years the average is less than two-thirds as much as for the first period of eight years.

Excluding the first eight years of the growth of wheat, the average annual yield of nitrogen over the next twenty-four years was 19.3 pounds per acre per annum; and the table shows that over the same twenty-four years, barley without manure yielded 18.3 pounds, and whilst with the wheat the decline in yield was from 22.6 pounds over the first twelve of the twenty-four years to 15.9 over the second twelve, it was with the barley from 22.0 to 14.6 pounds, or almost in the same proportion.

It might be objected that here the evidence is not conclusive that the falling off is due to the gradual reduction in the amount of nitrogen annually available from the soil. But the results with the two crops, where there is a liberal supply of mineral constituents every year, exclude the supposition that the decline is due to the exhaustion of mineral constituents. Thus, over the same twenty-four years, with a complex mineral manure, such as is very effective when there is artificial supply of nitrogen also, the yield of nitrogen in the wheat falls off from 27.0 pounds per acre per annum over the first twelve years, to 17.2 pounds over the second twelve years; and that in the barley, over the same two periods, from 26.0 to 18.8 pounds. The similarity in the actual yield, and in the rate of decline of yield, of nitrogen over the same periods in these two closely allied crops, though growing in different fields, and with somewhat different previous manurial history, is very striking. The slightly higher yield in both cases with than without the mineral manure is doubtless due to more complete utilization of the previous accumulations within the soil, and not to increased assimilation from atmospheric sources.

YIELD OF NITROGEN IN ROOT CROPS.

We now come to the yield of nitrogen by plants of other natural families, and the first of such results relate to the so-called "root crops"—turnips of the natural order Cruciferæ, and sugar-beet, and mangel-wurzel of the order Chenopodiaceæ. The table records the results for thirty-six years in succession, 1845–1880; but it should be stated that during three of those years barley was interposed without any manure in order, as far as possible, to equalize the condition of the land before rearranging the manuring, and during two other years the turnips failed, and there was no crop. It should be further explained, that without manure of any kind root crops, after a few years, give scarcely any pro-

duce at all, and hence the results recorded are those obtained by the use of mineral manures, but without any supply of nitrogen.

During the first eight years (four years Norfolk whites and four years Swedes) the turnips gave an average of 42 pounds of nitrogen per acre per annum, or very much more than either of the cereal crops. During the next three years barley yielded 24.3 pounds, or even somewhat less than the yield in wheat or barley with mineral manures in the earlier years of their continuous growth. During the next fifteen years (thirteen with Swedish turnips and two without any crop) the yield was reduced to 18.5 pounds; during the next five years, with sugar-beet, to 13.1 pounds; and during the last five years, to 1880 inclusive, to 15.4 pounds. Lastly, over the whole thirty-six years the average annual yield of nitrogen was 25.2 pounds.

Here, then, compared with wheat or barley, we have with the root crops, the growth of which extends much further into the autumn months, a much higher annual yield of nitrogen in the earlier years, and with this a much more rapid rate of decline subsequently, the annual yield over the last ten years being only about one-third as much as over the first eight years, whilst the yield in the later years is actually less than in either wheat or barley with the same complex mineral manure. Here, again, the marked decline in the yield of nitrogen, with liberal mineral manuring, points to a deficiency in the available supply of nitrogen itself as the cause of the deficient assimilation of it by the crop.

It may here be observed that those who maintain that the atmosphere is an important source of the nitrogen of our crops assume that the root crops, if provided with a small quantity of nitrogenous manure to favor the early development of the plant, will obtain the remainder from the atmosphere. How far this is the case may be illustrated by the following results, which are the average of five years' successive growth of mangel-wurzel on the same plots, and in each case with the same manure year after year.

TABLE II.—*Average produce of mangel-wurzel five years,* 1876—1880

	Roots.		Leaves.	
	Tons.	*Cwts.*	*Tons.*	*Cwts.*
1. Superphosphate of lime, and sulphate potassium	4	10	1	0
2. As 1, and 36½ pounds ammonia salts (=7.8 pounds N.)	6	0	1	6
3. As 1, and 400 pounds ammonia salts (=86 pounds N.)	14	0	2	16

Thus, the annual application of about 7.8 pounds of nitrogen, as ammonia salts, has increased the crop of roots by only 30 cwts. per acre per annum, and the increased yield of nitrogen in the crop was even somewhat less than the amount supplied in the manure. An application of 86 pounds of nitrogen has, however, increased the crop by 160 cwts. more. It is obvious from these facts that the small application of

nitrogen did not enable the plant to take up any from atmospheric sources, and that it required further direct supply of nitrogen to obtain further increase of crop. These results obviously afford confirmation of the view that it was a reduction of the available supply of nitrogen within the soil that was the cause in the decline in the annual yield of the crop and of the amount of nitrogen contained in it.

YIELD OF NITROGEN IN LEGUMINOUS CROPS.

We next come to the consideration of the yield of nitrogen in crops of the leguminous family when these are grown separately year after year on the same land. Plants of this family are said to rely almost exclusively on atmospheric sources for their nitrogen.

Table I shows that without manure beans gave an annual yield over the first twelve years of 48.1 pounds of nitrogen, but over the second twelve of only 14.6 pounds. Over the first period, therefore, the yield was about twice as much as in either wheat or barley, and more even than with the roots. But with this greater yield in the earlier years the reduction is proportionally much greater over the second period, the yield then coming down to less than one-third, and to much the same as in the later periods with the other crops. Over the whole period of twenty-four years, however, there was an annual yield of 31.3 pounds of nitrogen, or more than one and a half times as much as with either wheat or barley, and more than in the roots.

It was seen that in the case of the cereal crops the mixed manure increased the yield of nitrogen but little. Not so in the case of the leguminous crop, beans. During the first twelve years the complex mineral manure (containing a large amount of potash) yielded 61.5 pounds of nitrogen per acre per annum against 48.1 pounds without manure. During the next twelve years the mineral manure gave 29.5 pounds against only 14.6 pounds without manure. During the whole period of twenty-four years the potash manure yielded 45.5 pounds of nitrogen per acre per annum against 31.3 pounds without manure. Lastly, with the mixed mineral manure beans have yielded over a period of twenty-four years more than twice as much nitrogen per acre as either wheat or barley.

But notwithstanding that the beans have for a long series of years yielded so very much more nitrogen over a given area than either of the gramineous crops, and much more also than the root crops, the significant fact cannot fail to be observed that this crop of the leguminous family, which is supposed to rely almost exclusively on the atmosphere for its nitrogen, has declined in yield as strikingly as the other crops, even when grown by a complete mineral manure. Why should this be so if the supply of nitrogen is from the atmosphere and not from the soil?

The results next recorded relate to red clover, and the period of experiment was twenty-two years. It is well known that on most soils a

good crop of clover cannot be relied upon oftener than once in about eight years, and on many soils not so frequently. It will not excite surprise, therefore, that in the course of the twenty-two years of experiment, in only six was any crop of clover obtained, and in some of those only poor ones. Indeed, the plant failed nine times out of ten during the winter and spring succeeding the sowing of the seed. In one year a crop of wheat, and in three years barley, was taken instead; whilst in the remaining twelve years the land was left fallow after the failure of the clover. Still the annual yield of nitrogen over the twenty-two years was 30.5 pounds without any manure, and 39.8 pounds by a complex mineral manure containing potash. Unfavorable as is this result in an agricultural point of view, it is still seen that the interpolation of this leguminous crop has greatly increased the yield of nitrogen compared with that in either wheat or barley grown continuously; and here again, as with beans, a potash manure has considerably increased the yield.

The next experiment affords a still more striking illustration of the large amount of nitrogen that may be taken up in a clover crop; and it further illustrates the fact, well known in agriculture, that the removal of this highly nitrogenous leguminous crop is one of the best possible preparations for the growth of a cereal crop, which characteristically requires nitrogenous manuring. A field which had grown six corn crops in succession by artificial manures alone was then divided, and (in 1873) on one half barley and on the other half clover was grown. The barley yielded 37.3 pounds of nitrogen per acre, but the three cuttings of clover yielded 151.3 pounds. In the next year (1874) barley was grown on both portions of the field. Where barley had previously been grown, and had yielded 37.3 pounds of nitrogen per acre, it now yielded 39.1 pounds; but where the clover had previously been grown, and had yielded 151.3 pounds of nitrogen, the barley succeeding it gave 69.4 pounds, or 30.3 pounds more after the removal of 151.3 pounds in clover than after the removal of only 37.3 pounds in barley. It will be seen further on that this curious result was not in any way accidental.

YIELD OF NITROGEN BY A ROTATION OF CROPS.

The last results recorded in the table relate to the yield of nitrogen in an ordinary four-course rotation of turnips, barley, clover or beans, and wheat. The average yield per annum is given for seven courses, or for a period of twenty-eight years, in one case without any manure during the whole of that time, and in the other with superphosphate of lime alone, applied once every four years, that is, for the turnips commencing each course.

Here with a turnip crop, and a leguminous crop, interpolated with two cereal crops, we have without manure of any kind an average of 36.8 pounds of nitrogen per acre per annum, or very much more than was obtained in either of the cereal crops grown consecutively. With

superphosphate of lime alone, which much increased the yield of nitrogen in the turnips, reduced it in the succeeding barley, increased it greatly in the leguminous crops, and slightly in the wheat succeeding them, the average annual yield of nitrogen is increased to 45.2 pounds, or to about double that obtained in either wheat or barley grown consecutively by a complete mineral manure. On this point it may be further remarked that in adjoining experiments, in which, instead of a leguminous crop, the land was fallowed in the third year of each course, the total yield of nitrogen in the rotation was very much less. In other words, the removal of the most highly nitrogenous crops of the rotation—beans or clover—was succeeded by a growth of wheat, and an assimilation of nitrogen by it, almost as great as when it succeeded a year of fallow; that is, a period of accumulation, and of no removal by crops.

YIELD OF NITROGEN IN THE HERBAGE OF GRASS-LAND.

Another illustration of the amounts of nitrogen removed from a given area of land by different descriptions of crop will be found in Table III, which shows the results obtained when plants of the gramineous, the leguminous, and other families are grown together in the mixed herbage of grass-land.

TABLE III.—*Yield of nitrogen in the mixed herbage of permanent grass-land at Rothamsted.*

Plots.	Conditions of manuring.	Average produce per acre per annum, twenty years, 1856–1875, according to mean per cent., at six periods, 1862, '67, '71, '72, '74, '75.			Average nitrogen per acre per annum.		
		Gramineæ.	Leguminosæ.	Other orders.	Ten years, 1856–1865.	Ten years, 1866–1875.	Twenty years, 1856–1875.
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
3	Unmanured	1,635	219	529	35.1	30.9	33.0
4-1	Superphosphate*	1,671	149	673	35.7	31.5	33.6
8	Complex min. man.†	2,443	296	639	54.4	38.1	46.3
7	Complex min. man.‡	2,579	806	573	55.2	56.0	55.6

* Mean of four separations only, namely, 1862, 1867, 1872, and 1875.
† Including potass., six years, 1856–1861; without potass., fourteen years, 1862–1875.
‡ Including potass., twenty years, 1856–1875.

Before referring to the figures attention should be called to the fact that gramineous crops, grown separately on arable land, such as wheat, barley, or oats, contain a comparatively low percentage of nitrogen, and assimilate a comparatively small amount of it over a given area. Yet nitrogenous manures have generally a very striking effect in increasing the growth of such crops. The highly nitrogenous leguminous crops, on the other hand, such as beans and clover, yield, as has been seen, very much more nitrogen over a given area: yet they are by no means characteristically benefited by nitrogenous manuring, whilst their growth is considerably increased, and the yield considerably more nitrogen over

a given area, under the influence of purely mineral manures, and especially of potass. manures. Bearing these facts in mind, the results given in the table will be seen to be quite consistent.

The first three columns in the table show approximately how the mixed herbage was made up under the four different conditions of manuring. It will be observed that without manure, and with superphosphate of lime alone, the amount of the different descriptions of herbage are much the same. Plot 8, with a complex mineral manure including potass. the first six years, but excluding it the next fourteen years, gave a considerable increase of both gramineous and leguminous herbage; whilst plot 7, with a complex mineral manure, including potass. every year of the twenty, there is a still further increase of gramineous herbage, but a very much greater proportional increase of leguminous herbage. It will be observed how much greater is the increase of gramineous produce by the application of purely mineral manures to this mixed herbage than in the case of gramineous crops grown separately. It is a question how far this is due to the mineral manures enabling the grasses to form much more stem and seed, that is, the better to manure, which in fact they do, or how far to an increased amount of combined nitrogen in a condition available for the grasses in the upper layers of the soil, as the result of the increased growth of the Leguminosæ in the first instance, induced by the potass. manure, as in the case of the alternation of clover and barley, and as in the actual course of rotation.

To turn to the yield of nitrogen on the different plots of the mixed herbage, it will be seen that the amounts are almost identical without manure, and with superphosphate of lime alone, about 33 pounds per acre per annum. On plot 8, where a complex mineral manure, including potass. six years, but excluding potass. fourteen years, was employed, the amount is raised to 46.3 pounds, and on plot 7, which received the mixed mineral manure, including potass. every year of the twenty, the yield is 55.6 pounds per acre per annum. Further, without manure, and with superphosphate of lime alone, there was a decline in the yield in the later, compared with the earlier years: with the mineral manure, including potass. only in the first six years, there was a much more marked decline; whilst with the mineral manure, including potass. every year, there was even a slight tendency to an increased yield of nitrogen in the later years.

YIELD OF NITROGEN IN MELILOTUS LEUCANTHA.

One more striking illustration of high nitrogen yield by a plant ot the Leguminous family on soil which had not received any nitrogenous manure for nearly thirty years must be given. In 1878, the land upon which attempts had been made to grow red clover in frequent succession since 1849, was devoted to experiments with fourteen different descriptions of leguminous plants; so that the present season, 1882, is

the fifth year of the experiments. The object was to ascertain whether, among a selection of plants all of the Leguminous family, but of different habits of growth, and especially of different character and range of roots, some could be grown successfully for a longer time, and would yield more produce, containing more nitrogen as well as other constituents, than others; all being supplied with the same descriptions and quantities of manuring substances, applied to the surface soil. Further, whether the success in some cases and the failure in others, would afford additional evidence as to the source of the nitrogen of the Leguminosæ generally, and as to the causes of the failure of red clover in particular, when it is grown too frequently on the same land. Fourteen different descriptions of plants were selected, and after two or three immaterial changes the list now includes eight species or varieties of *Trifolium*, two of *Medicago*, *Melilotus leucantha*, *Lotus corniculatus*, *Vicia sativa*, and *Onobrychis sativa*.

Of the numerous species or varieties of *Trifolium* all gave but meager produce, excepting *T. incarnatum*. The *Lotus corniculatus* also gave very small produce. The two species of *Medicago*, the black *Medick*, and the purple *Medick* or Lucerne, and the *Onobrychis*, or common Sainfoin, gave much more; the *Vicia sativa* or common vetch, more still. But of all, the *Melilotus leucantha* or Bokhara clover has yielded the most; and it is estimated that, taking the average of four years, 1878–'81, it has yielded more than 100 pounds of nitrogen per acre per annum, on the plots which have received no nitrogenous manure for more than thirty years; whilst the produce of the fifth season, 1882, is heavier than either of the preceding years. How long this very luxuriant growth and this very high yield of nitrogen per acre will continue, is a question of very great interest. On this point it may be observed that in parts of the continent of Europe, where some of the very free-growing and deep-rooted Leguminosæ are cultivated, it is usual to let them grow for several years, after which they cannot be repeated for twenty years or more. We shall recur to the results above quoted further on.

SUMMARY OF YIELD OF NITROGEN IN CROPS.

The foregoing facts of production, showing the yield of nitrogen in different crops grown without nitrogenous manure, generally for very many years in succession on the same land, may be briefly summed up as follows:

The average yield of nitrogen per acre per annum, was, with wheat, thirty-two years without manure, 20.7 pounds, and twenty-four years with a complex mineral manure, 22.1 pounds; with barley, twenty-four years without manure, 18.3 pounds, and twenty-four years with a complex mineral manure, 22.4 pounds; with root-crops, thirty-six years (including three of barley), with a complex mineral manure, 25.2 pounds; with beans, twenty-four years without manure, 31.3 pounds, and twenty-

four years with a complex mineral manure, 45.5; with clover, six crops in twenty-two years, with one crop of wheat, three crops barley, and twelve years fallow, without manure, 30.5 pounds; with complex mineral manure, 39.8 pounds; with clover on land which had not grown the crop for very many years, one year, 151.3 pounds; with a rotation of crops, seven courses, twenty-eight years without manure, 36.8 pounds; with superphosphate of lime, 45.2 pounds; with the mixed herbage of grass land, twenty years without manure, 33 pounds, and with complex mineral manure, including potass, 55.6; lastly, with Bokhara clover, four years, with mineral manure, more than 100 pounds of nitrogen per acre per annum.

The root-crops yielded more nitrogen than the cereal crops, and the leguminous crops very much more still.

In all the cases of the experiments on ordinary arable land—whether with cereal crops, root crops, leguminous crops, or a rotation of crops (excepting as yet the Bokhara clover)—*the decline in the annual yield of nitrogen, none being supplied* by manure, was very great.

SOURCES OF THE NITROGEN OF CROPS.

We must next consider whence comes the nitrogen of the crops, and especially whence comes the much larger amount taken up by plants of the leguminous, and some other families, than by the gramineæ. Lastly, what is the significance of the great decline in the yield of nitogen in all the crops grown on arable land when none is supplied in the manure?

COMBINED NITROGEN IN RAIN, ETC.

It has been assumed by some that the amount of combined nitrogen annually coming down in the measured aqueous deposits from the atmosphere is sufficient for all the requirements of annual growth. In Liebig's earlier writings he assumed the probability of a very much larger quantity of ammonia coming down in rain than he did subsequently; but even in his more recent work, "The Natural Laws of Husbandry," published in 1863, he supposes that as much as 24 pounds of nitrogen per acre may be annually available to vegetation from that source. Such an amount would, it is obvious, do much towards meeting the requirements of most of the crops the nitrogen statistics of which have been given.

The earliest considerable series of determinations of the amount of ammonia coming down in rain in the open country were by Boussingault, in Alsace. He gives the amount of ammonia per million of rain-water in each fall for a period of between five and six months, May–October, 1852; but he does not calculate the amount so coming down over a given area of land. His average amount per million was, however, somewhat less than that found at Rothamsted in 1853 and 1854, and

found by Mr. Way in Rothamsted rain-water collected in 1855 and 1856; which, calculated according to the rain-fall of the periods, give the following amounts of nitrogen so coming down per acre. The amounts of nitrogen as nitric acid, as determined by Mr. Way, and the amount of total combined nitrogen as ammonia and nitric acid together, are also given.

TABLE IV.—*Nitrogen, as ammonia, and nitric acid, in the rain-fall of three years, at Rothamsted, in pounds per acre.*

Years.	Rainfall.	Nitrogen per acre, as—		
		Ammonia.	Nitric acid.	Total nitrogen.
	Inches.	*Pounds.*	*Pounds.*	*Pounds.*
1853–'5	29.014	5.20	(0.74)	5.94
1855	29.166	5.82	0.72	6.58
1856	27.215	7.28	0.76	8.00
Mean	28.465	6.10	0.74	6.84

It will be seen that according to these results an average of 6.84 pounds was contributed per acre per annum in the rain in the form of ammonia and nitric acid. More recently, however, Dr. Frankland has determined the amount of ammonia and nitric acid in numerous samples of rain and snow water, dew, hoar frost, &c., collected at Rothamsted from April, 1869, to May, 1870, inclusive; and the average amount of ammonia per million of water found by him is considerably lower than the earlier determinations show. More recently still the ammonia has been determined in the Rothamsted laboratory, in the rain of each day separately (if any), for a period of six months, July–December, 1881; also in the proportionally mixed rain for each month, for a period of thirteen months, June, 1881, to June, 1882. The average proportion of ammonia in these most recent determinations accords with the results of Frankland, and point to a smaller amount of total combined nitrogen supplied per acre in the average annual rain-fall at Rothamsted than that recorded in the table; probably, indeed, to not more than four or five pounds of total combined nitrogen per acre per annum.

Dr. R. Angus Smith, in his work entitled "Air and Rain the Beginnings of a Chemical Climatology," 1872, gives the results of numerous analyses of rain-water collected both in country and town districts in the United Kingdom. The amounts of ammonia and nitric acid in the rain vary exceedingly, according to locality; but the amounts in the rain of country places accords generally with those found in the Rothamsted rain-fall.

The following table summarizes the results of numerous determinations made at various stations on the continent of Europe, in each case extending over a whole year:

TABLE 5.—*Nitrogen as ammonia and nitric acid in the rain of various localities in Europe.*

[Quantities in pounds per acre per annum.]

Localities.	Years.	Rain-fall.	Nitrogen as— Ammonia.	Nitric acid.	Total.
		Inches.	*Pounds.*	*Pounds.*	*Pounds.*
Kuschen	1864–'65	11.85	1.44	0.42	1.86
Do	1865–'66	17.70	1.83	0.67	2.50
Insterburg	1864–'65	27.55	3.55	1.94	5.49
Do	1865–'66	23.79	4.14	2.67	6.81
Dahme	1865	17.09	5.50	1.16	6.66
Regenwalde	1864–'65	23.48	10.82	4.27	15.09
Do	1865–'66	19.31	8.27	2.11	10.38
Do	1866–'67	25.37	13.20	3.24	16.44
Ida-Marienhütte; mean six years	1865–'70	22.65	....	....	9.92
Proskaw	1864–'65	17.81	13.58	7.33	20.91
Florence	1870	36.55	9.71	3.65	13.36
Do	1871	42.48	7.78	2.11	9.89
Do	1872	50.82	9.50	3.01	12.51
Vallombrosa	1872	79.83	7.65	2.73	10.38
Montsouris, Paris	1877–'78	23.62	10.25	1.29	11.54
Do	1878–'79	25.79	7.05	4.11	11.16
Do	1879–'80	15.70	4.83	5.69	10.52
Mean, twenty-two years		27.03	....	......	10.23

It is seen that the numerous very widely varying determinations, some made in the vicinity of towns and some in the open country, give a mean of 10.23 pounds of combined nitrogen annually supplied per acre by rain with a mean rainfall of 27.03 inches. Making all allowance for far inland open country positions on the one hand and for proximity to towns on the other, the very small amounts of combined nitrogen so supplied per acre in some of the cases and the comparatively large quantities in others seem difficult to explain or to reconcile, either with one another or with the results of Boussingault and of Rothamsted. When, however, the comparatively limited and uniform amounts recorded for Montsouris, within the walls of Paris, are considered. 11.54 pounds, 11.16 pounds. and 10.52 pounds per acre per annum, it will not excite surprise that we should estimate the amount of combined nitrogen coming down in the measured aqueous deposits from the atmosphere at probably not more than 5 pounds per acre per annum in the open country at Rothamsted.

With records of the amounts of combined nitrogen contributed to a given area in rain, we come to an end of all quantitative evidence as to the amount of combined nitrogen available to the vegetation of a given area from atmospheric sources. It will be seen how entirely inadequate is the amount probably so available to supply the quantities yielded in different crops without nitrogenous manure, as recorded in the table.

It is true that the minor aqueous deposits from the atmosphere are much richer in combined nitrogen than rain, and there can be no doubt that there would be more deposited within the pores of a given area of soil than on an equal area of the porous even surface of a rain gauge.

How much, however, of this might be available beyond that determined in the collected aqueous deposits, existing evidence does not afford the means of estimating with certainty.

OTHER SUPPOSED SOURCES OF COMBINED NITROGEN.

Further, it has been argued that, in the last stages of the decomposition of organic matter in the soil, hydrogen is evolved, and that this nascent hydrogen combines with the free nitrogen of the atmosphere, and so forms ammonia. Again, it has been suggested that ozone may be evolved in the oxidation of organic matter in the soil, and that, uniting with free nitrogen, nitric acid would be produced.

We have discussed these various possible supplies of combined nitrogen to the soil from atmospheric sources on more than one occasion; and we have given our reasons for concluding that none of them can be taken as accounting for the facts of growth. Incidentally, some evidence will be given further on, confirming the conclusion that any such supplies are limited and inadequate.

But, if the supplies from the atmosphere to the soil itself are inadequate, how about the direct supplies from the atmosphere to the plant?

One view which has been advocated is, that broad-leaved plants have the power of taking up combined nitrogen from the atmosphere, in a manner or in a degree not possessed by the narrow leaved gramineous plants. The only experiments that we are aware of made to determine whether plants can take up nitrogen by their leaves from ammonia supplied to them in the ambient atmosphere are those of Adolph Mayer in Germany, and of Schlössing in France. Both found that very small quantities of nitrogen were so taken up; but both concluded that the action takes place in very immaterial degree in natural vegetation. We have elsewhere shown that not only a consideration of the chemistry and the physics of the subject would lead to the conclusion that the plants which assimilate more nitrogen over a given area than others do not do so by virtue of a greater power of absorbing already combined nitrogen from the atmosphere by their leaves. But, apart from such considerations, our statistics of nitrogen production seem to preclude the idea that the broad-leaved root crops, turnips, and the like, to which the function has with the most confidence been attributed, take up any material proportion of their nitrogen by their leaves from combined nitrogen in the atmosphere. We need only here recall attention to the fact that the yield of nitrogen in these crops, even with the aid of a complex mineral manure, was in the later years reduced to as low a point as in the case of the narrow-leaved cereals.

DO PLANTS ASSIMILATE FREE NITROGEN?

The question still remains whether plants assimilate the free nitrogen of the atmosphere, and whether some descriptions do so in a much greater degree than others. It is freely admitted that if this were established many of our difficulties would vanish.

This question has been the subject of a great deal of experimental inquiry, since the time that Boussingault entered upon it about the year 1837; and more than twenty years ago it was elaborately investigated at Rothamsted.

We will here give a summary of the very conflicting results which have been published in reference to this subject of the assimilation of the free nitrogen of the atmosphere by plants, confining attention for want of space to the three most comprehensive series of experiments which have been undertaken relating to it.

Though not the first in point of date, we will first refer to the experiments of M. G. Ville, the results of which led him to conclude that plants do assimilate the free nitrogen of the air—a view of which he has been the archapostle for many years, and upon which he may be said to have founded a system in his work on "Artificial Manures."

From 1849 to 1856, M. G. Ville made numerous experiments on this subject. The following table (V) gives a summary of his results, and shows the special conditions of each separate series of experiments:

TABLE V.—*Results of M. G. Ville's experiments to determine whether plants assimilate free nitrogen.*

Plots.	Nitrogen, grams.			Nitrogen in products to 1 supplied.
	In seed and air, and manure, if any.	In products.	Gain or loss.	
1849. Current of unwashed air supplying 0.001 grams nitrogen as ammonia: (1)				
Cress	0.0260	0.1470	0.1210	5.6
Large lupins	0.0640	0.0640	0.0000	1.0
Small lupins	0.0640	0.0470	—0.0170	0.7
	0.1550	0.2580	0.1030	1.7
1850. Current of unwashed air supplying 0.0017 grams nitrogen as ammonia: (1)				
Colza (plants)	0.0260	1.0700	1.0440	41.1
Wheat	0.0160	0.0310	0.0150	1.9
Rye	0.0130	0.0370	0.0240	2.8
Maize	0.0290	0.1280	0.0990	4.4
	0.0857	1.2660	1.1803	14.8
1851. Current of washed air: (1)				
Sunflower	0.0050	0.1570	0.1520	31.4
Tobacco	0.0040	0.1750	0.1710	43.7
Tobacco	0.0040	0.1620	0.1580	40.5
1852. Current of washed air: (1)				
Autumn colza	0.0480	0.2260	0.1780	4.7
Spring wheat	0.0290	0.0650	0.0360	2.2
Sunflower	0.0160	0.4080	0.3920	25.5
Summer colza	0.1730	0.5950	0.4220	3.4
Summer colza	0.1050	0.7010	0.5960	6.7
1854. Current of washed air (under superintendence of a commission):				
Cress	0.0099	0.0097	—0.0002	1.0
Cress	0.0038	0.0530	0.0492	13.9
Cress	0.0039	0.0110	0.0071	2.
1854. Current of washed air (closed under superintendence of a commission): (2)				

(1) Recherches Experimentates sur la Végétation, par M. Georges Ville. Paris, 1853.
(2) Compt. rend.: 1855.

TABLE V—Continued.

Plots.	Nitrogen, grams. In seed and air, and manure, if any.	Nitrogen, grams. In products.	Nitrogen, grams. Gain or loss.	Nitrogen in products to 1 supplied.
Cress	0.0063	0.0350	0.0 87	5.6
1855 and 1856. In pure air, with 0.5 gram nitre = 0.069 nitrogen: (1)				
Colza	0.0700	(2)0.0700	0.0000	1.0
Colza	0.0700	(2)0.0660	—0.0040	0.9
Colza	0.0700	(2)0.0680	—0.0020	1.0
1855 and 1856. In free air, with 1 gram nitre = 0.138 nitrogen: (1)				
Colza	0.1400	(2)0.1970	0.0570	1.41
Colza	0.1400	(2)0.3740	0.2340	2.67
Colza	0.1400	(2)0.2160	0.0760	1.54
Colza	0.1400	(2)0.2500	0.1100	1.79
1856. In free air, with 0.792 gram nitre = 0.110 nitrogen: (1)				
Wheat	0.1260	(2)0.2180	0.0920	1.7
Wheat	0.1260	(2)0.2240	0.0980	1.8
1855. In free air, with 1.72 grams nitre = 0.238 nitrogen: (1)				
Wheat	0.2590	(2)0.3080	0.0490	1.2
1856. In free air, with 1.765 grams nitre = 0.244 nitroge: (1)				
Wheat	0.2650	(2)0.2170	—0.0480	0.8
Wheat	0.2650	(2)0.3500	+0.0850	1.3

(1) Recherches Experimentales sur la Végétation, 1857.
(2) In plants only.

These results, as well as those of others, we have fully discussed elsewhere (Phil. Trans., 1859, and Jour. Chem. Soc., vol. xvi. 1863), and we can only very briefly refer to them in this place.

The column of actual gain or loss, shows in one case, with colza, a gain of more than 1 gram of nitrogen; and the amount in the products is more than forty-one times as much as that supplied as combined nitrogen in the seed and air. The results with wheat, rye, or maize showed very much less of both actual and proportional gain. Experiments with sunflower showed in one case thirty fold, and with tobacco in two cases more than forty fold, as much in the products as was supplied. It will be observed, however, that upon the whole M. G. Ville's later experiments showed considerably less both actual and proportional gain than his earlier ones.

M. G. Ville in some cases attributed the gain to the large leaf surface. In explanation of the assimilation of free nitrogen by plants, he calls attention to the fact that nascent hydrogen is said to give ammonia, and nascent oxygen nitric acid, with free nitrogen, and he asks: Why should not the nitrogen in the juices of the plant combine with the nascent carbon and oxygen in the leaves? He refers to the supposition of M. De Luca, that the nitrogen of the air combines with the nascent oxygen given off by the leaves of plants, and to the fact that the juice of some plants (mushrooms) has been observed to ozonize the oxygen of the air, and he asks: Is it not probable, then, that the nitrogen dissolved in the juices will submit to the action of the ozonized oxygen with which it is mixed, when we bear in mind that the juices contain alkalies, and penetrate tissues, the porosity of which exceeds that of spongy platinum?

The following table (VI) summarizes the results of M. Boussingault. His experiments on the subject commenced in 1837, and were continued at intervals up to 1858. The conditions of each set of experiments as to soil, air, or application of manurial substances, are given in the table.

TABLE VI.—*Results of M. Boussingault's experiments to determine whether plants assimilate free nitrogen.*

Plants.	Nitrogen, grams. In seed or plants, and manure, if any.	In manure.	Gain or loss.	Nitrogen in products to 1 supplied.
1837. Burnt soil, distilled water, free air in closed summer house: (1)				
Trefoil	0.1100	0.1200	+0.0100	1.09
Trefoil	0.1140	0.1560	+0.0420	1.37
Wheat	0.0430	0.0400	—0.0030	0.93
Wheat	0.0570	0.0600	+0.0030	1.05
1838. Conditions as in 1837: (2)				
Peas	0.0460	0.1010	+0.0550	2.20
Trefoil (plants)	0.0330	0.0560	+0.0230	1.70
Oats (plants)	0.0590	0.0530	—0.0060	0.90
1851 and 1852. Washed and ignited pumice with ashes, distilled water, limited air, under glass shade, with carbonic acid: (3)				
Haricot, 1851	0.0349	0.0340	—0.0009	0.97
Oats, 1851	0.0078	0.0067	—0.0011	0.86
Haricot, 1852	0.0210	0.0189	—0.0021	0.90
Haricot, 1852	0.0245	0.0226	—0.0019	0.92
Oats, 1852	0.0031	0.0030	—0.0001	0.97
1853. Prepared pumice, or burnt brick, with ashes; distilled water, limited air, in glass globe, with carbonic acid: (3)				
White lupin	0.0480	0.0483	+0.0003	1.01
White lupin	0.1282	0.1246	—0.0036	0.97
White lupin	0.0349	0.0339	—0.0010	0.97
White lupin	0.0200	0.0204	+0.0004	1.02
White lupin	0.0399	0.0397	—0.0002	1.00
Dwarf haricot	0.0354	0.0360	+0.0006	1.02
Dwarf haricot	0.0298	0.0277	—0.0021	0.93
Garden cress	0.0013	0.0013	0.0000	1.00
White lupin	0.1827	0.1697	—0.0130	0.93
1854. Prepared pumice with ashes, distilled water, current of washed air, and carbonic acid, in glazed case: (4)				
Lupin	0.0196	0.0187	—0.0009	0.95
Dwarf haricot	0.0322	0.0325	+0.0003	1.01
Dwarf haricot	0.0335	0.0341	+0.0006	1.02
Dwarf haricot	0.0339	0.0329	—0.0010	0.97
Dwarf haricot	0.0676	0.0666	—0.0010	0.99
Lupin Lupin	0.0180 0.0175	0.0334	—0.0021	0.94
Cress	0.0046	0.0052	—0.0006	1.13
1851, '52, '53, and '54. Prepared soil, or pumice with ashes; distilled water, free air, under glazed case: (4)				
Haricot (dwarf), 1851	0.0349	0.0380	+0.0031	1.09
Haricot, 1853	0.0213	0.0238	+0.0025	1.12
Haricot, 1853	0.0293	0.0270	—0.0023	0.92
Haricot (dwarf), 1854	0.0318	0.0350	+0.0032	1.10
Lupin (white), 1853	0.0214	0.0256	+0.0042	1.20
Lupin, 1854	0.0199	0.0229	+0.0030	1.15
Lupin, 1854	0.0367	0.0387	+0.0020	1.05
Oats, 1852	0.0031	0.0041	+0.0010	1.32
Wheat, 1853	0.0064	0.0075	+0.0011	1.17
Garden cress, 1854	0.0259	0.0272	+0.0013	1.05
1858. Nitrate of potassium as manure: (5)				
Helianthus	(6) 0.0144 (6) 0.0255	0.0130 0.0245	—0.0014 —0.0010	0.90 0.96

(1) Ann. Ch. Phys. [2], lxvii (1838).
(2) Ibid, lxix.
(3) Ann. Ch. Phys. [3], xli (1854).
(4) Ann. Ch. Phys. Ser. [3], xliii (1855).
(5) Compt. rend., xlvii (1858).
(6) Nitrogen in seed and nitrate.

The last two columns of the table ( ) show the actual and proportional gain or loss of nitrogen in M. Boussingault's experiments. It will be seen that in his earlier experiments, those in free air in a summer house, the leguminous plants, trefoil and peas, did indicate a notable gain of nitrogen: but in all his subsequent experiments there was generally either a slight loss, or, if a gain, it was represented in only, fractions or low units of milligrams. After twenty years of varied and laborious investigation of the subject, M. Boussingault concluded that plants have not the power of assimilating the free nitrogen of the atmosphere. And in a letter received from him as recently as 1876, after discussing several aspects of the question, he says:

> If there is one fact perfectly demonstrated in physiology, it is this of the non-assimilation of free nitrogen by plants: and I may add by plants of an inferior order, such as micoderms and mushrooms.—(Translation.)

Our own experiments on this subject were commenced in 1857, and a young American chemist, the late Dr. Pugh, of the Pennsylvania State Agricultural College, devoted between two and three years to the investigation at Rothamsted. The conditions of the experiments and the results obtained up to that date are fully described in the papers in the Philosophical Transactions for 1859 and in the Journal of the Chemical Society, in 1863, already referred to. Table VII summarizes the results obtained.

TABLE VII.—*Results of experiments made at Rothamsted to determine whether plants assimilate free nitrogen.*

With *no* combined nitrogen supplied beyond that in the seed sown.

	Nitrogen, grams.			Nitrogen in products to 1, supplied.
	In seed and manure, if any.	In plants, pot, and soil.	Gain or loss.	
GRAMINEÆ.				
1857:				
Wheat	0.0080	0.0072	−0.0008	0.90
Barley	0.0056	0.0072	+0.0016	1.11
Do	0.0056	0.0082	+0.0026	1.46
1858:				
Wheat	0.0078	0.0081	+0.0003	1.04
Barley	0.0057	0.0058	+0.0001	1.02
Oats	0.0063	0.0056	−0.0007	0.89
1858, A 1:				
Wheat	0.0078	0.0078	0.0000	1.00
Oats	0.0064	0.0063	−0.0001	0.98
LEGUMINOSÆ.				
1857:				
Beans	0.0796	0.0791	−0.0005	0.99
1858:				
Beans	0.0750	0.0757	+0.0007	1.01
Pease	0.0188	0.0167	−0.0021	0.89
OTHER PLANTS.				
1858:				
Buckwheat	0.0200	0.0182	−0.0018	0.91

TABLE VII—Continued.

With combined nitrogen suppiled beyond that in the seed sown.

	Nitrogen, grams.			Nitrogen in products to 1, supplied.
	In seed and manure, if any.	In plants, pot, and soil.	Gain or loss.	
GRAMINEÆ.				
1857:				
Wheat	0.0329	0.0383	+0.0054	1.16
Do	0.0329	0.0331	+0.0002	1.01
Barley	0.0326	0.0328	+0.0002	1.01
Do	0.0268	0.0337	+0.0069	1.25
1858:				
Wheat	0.0548	0.0536	−0.0012	0.98
Barley	0.0496	0.0464	−0.0032	0.94
Oats	0.0312	0.0216	−0.0096	0.69
1858, A 1:				
Wheat	0.0268	0.0274	+0.0006	1.02
Barley	0.0257	0.0242	−0.0015	0.94
Oats	0.0260	0.0198	−0.0062	0.76
LEGUMINOSÆ.				
1858:				
Pease	0.0227	0.0211	−0.0016	0.93
Clover	0.0712	0.0665	−0.0047	0.93
1858, A 1:				
Beans	0.0711	0.0655	−0.0056	0.92
OTHER PLANTS.				
1858:				
Buckwheat	0.0308	0.0292	−0.0016	0.95

A 1. These experiments were conducted in the apparatus of M. G. Ville.

The upper part of the table shows the results obtained in the experiment in which no combined nitrogen was supplied beyond that contained in the seed sown. The growth was in all cases extremely restricted, and the figures show that there was in no case, whether of gramineæ, leguminosæ, or buckwheat, a gain indicated by as much as three milligrams of nitrogen. There was in most cases much less gain or a slight loss.

The lower part of the table shows the results obtained when the plants were supplied with known quantities of combined nitrogen in the form of a solution of ammonium sulphate applied to the soil. The actual gains or losses range a little higher in these experiments, with larger quantities of nitrogen involved; but they are always represented by units of milligrams only, and the losses are higher than the gains. Further, the gains, such as they are, are all in the experiments with the gramineæ, whilst there is in each case a loss with the leguminosæ and the buckwheat.

It should be stated that the growth was far more healthy with the gramineæ than with the leguminosæ, which are even in the open field very susceptible to vicissitudes of heat and moisture, and were especially so when inclosed under glass shades. It might be objected, therefore, that the negative results with the leguminosæ are not so conclu-

sive as those with the gramineæ. Nevertheless, we do not hesitate to conclude from our own experiments, as Boussingault did from his, that the evidence is strongly against the supposition that either the gramineæ or the leguminosæ assimilate the free nitrogen of the atmosphere.

RECAPITULATION.

In the foregoing resumé of mostly previously recorded fact, we have shown the amount of nitrogen assimilated by various crops over a given area when grown for many years in succession on the same land without any nitrogenous manure; that is, under conditions in which the source of the nitrogen is as little as possible obscured by the influence of indefinite amounts available from manure. It has been shown that the determined amounts of combined nitrogen annually coming down in the measured aqueous deposits from the atmosphere in the open country are entirely insufficient to do more than supply a small proportion of the nitrogen assimilated by crops so grown. With regard to other possible supplies of already combined nitrogen from the atmosphere to the soil, it has been pointed out that there is no quantitative evidence whatever at command, and that such evidence as does exist leads to the conclusion that such supplies are very limited and inadequate. The same may be said, even in a greater degree, of the supposed combination of the free nitrogen of the air within the soil; also of the supposition that plants take up any material proportion of their nitrogen from combined nitrogen in the atmosphere by their leaves. Finally it has been concluded that the balance of direct experimental evidence is decidedly against the supposition that plants assimilate the free nitrogen of the atmosphere. Indeed, the strongest argument that we know of in favor of such a supposition is that, in defect of other conclusive evidence, some such explanation of the facts of production would seem to be needed.

THE NITROGEN OF THE SOIL A SOURCE OF THE NITROGEN OF CROPS.

We now turn to that part of the subject which it is the special object of this communication to bring forward, namely, the determinations of nitrogen in the soils of some of the experimental fields at Rothamsted, the yield in nitrogen of which has been given, and to show the bearing of the results on the question of the sources of the nitrogen of the crops.

We have no wish or intention to ignore the difficulties inherent in the treatment of the subject from this point of view. The difficulty of the problem will at once be recognized when it is borne in mind that a difference of .001 in the percentage of nitrogen in the dry soil may represent a difference of from 20 to 25 pounds of nitrogen per acre, in a layer of 9 inches in depth. Again, when it is further borne in mind that, in the case of the Rothamsted arable soils with which we have to deal, the percentage of nitrogen in the first 9 inches of depth is sometimes

only about 0.1, and seldom exceeds .14 or .15; that the percentage in the second 9 inches ranges from under .06 to about .07, and that that of the lower depths is rather lower still, it will be seen that if any quantitative estimates are to be based on the percentage amounts of nitrogen determined in samples of soil from different depths, the greatest care must be taken to insure that the samples truly represent the exact depth supposed. The mode usually adopted of taking samples of an indefinite area, perhaps not to a definite depth, and almost certainly not of uniform breadth or width to the depth taken, is obviously quite inapplicable for the purposes of any such inquiry as that supposed.

Unfortunately, the few samples of soil that were collected in the early years of the Rothamsted field experiments were not taken in such a manner as to afford results applicable to our purpose. Commencing in 1856, however, the mode adopted has been, after carefully leveling the soil, to drive down a square frame, made of strong sheet iron, open at top and bottom, and of an exact area, and of an exact depth, to the level of the surface. The inclosed soil is then carefully taken out, and its weight determined. The soil around the frame is then removed to the level of its lower edge, and it is again driven down, and the inclosed soil removed; and this process is repeated until the desired depth of sampling is reached.

Of surface soils, samples are taken from three, four, or as many as eight places on the same plot. A portion of each such sample is kept separate, as a means of testing the range of variation, and, if need be, of correction in case of any abnormal results due to accidental animal droppings or other causes. Another portion of each separate sample is used to make a mixture of all. In the case of the subsoils, the separate samples of corresponding depth from the same plot are at once mixed. Surface soils are sometimes taken of an area of 12 by 12 inches, but sometimes of only 6 by 6 inches, and subsoils almost invariably of the smaller area. The depth of each sample is generally 9 inches; but in some special cases it has been only 3 inches, and in some 6 inches. It is perhaps to be regretted that the depth originally fixed upon did not more nearly represent that to which the soil is more directly affected by the mechanical operations, and by the application of manure, say 6 inches. But having originally adopted 9 inches, it has been necessary to adhere to this depth subsequently, in order, as far as possible, to obtain comparable results at different dates.

The soils when brought to the laboratory are first broken up and partially dried in a stove room at a temperature of about 130° F. to arrest nitrification, which would be liable to take place if the soils were moist. Next the stones are removed; first those retained by a sieve of 1-inch mesh, next by a sieve of one-half-inch mesh, and then by a one-fourth inch sieve. All that passes the one-fourth inch sieve is termed the *mold*. Portions of this are very finely powdered and sifted for ana-

lysis, and the weights being recorded at each stage of preparation, and the water lost on drying at 100 C being determined on the finely powdered mold, all results of analysis are calculated into percentage on the so-determined *dry mold.* From the same data the amount of *dry mold* per acre is calculated, and upon this the amount of nitrogen per acre. It will be seen further on, that notwithstanding the means adopted to secure uniformity, the amounts of dry mold per acre calculated for a given depth from the samples taken vary considerably for the same field at different times, according to the dryness or wetness of the season, the condition of the land as affected by the crop, the mechanical operations, and other circumstances. The amounts also vary very considerably for the soils of adjoining fields.

NITROGEN IN THE SOILS OF THE EXPERIMENTAL WHEAT PLOTS.

The first series of determinations of nitrogen to which attention will be called relates to those made in the soils of some of the plots of Broadbalk field, which has now grown wheat for thirty-nine years in succession, and the yield of nitrogen in which, on the plots receiving no nitrogen in manure, has been given in Table I. It will be remembered that, under those conditions, there was a very marked decline in the annual yield of nitrogen in the crop, both without any manure and with a mixed mineral manure used alone.

The first wheat crop of the series was harvested in 1844, and although isolated samples of the soil were taken in the early years, it was not until 1856 that any were collected on the plan now followed. At that date only four plots were sampled, and only to the depth of the first 9 inches. Eight samples were, however, taken from each plot, each 12 by 12 inches area, and the eight were mixed together. In 1865, samples were taken from eleven plots, from eight places on each plot, each sample 12 by 12 inches area, and this time to a depth three times 9 inches, or to a total depth of 27 inches. Lastly, in 1881, twenty plots were sampled; six samples, each 6 by 6 inches area, were taken from each plot, and in each case to three depths of 9 inches each, or in all to 27 inches.

Thus, it is only in 1865 and in 1881 that we have any considerable series of samples and the nitrogen determined in them: that is, in 1865 after the twenty-second, and in 1881 after the thirty-eighth crop had been removed. It is obvious that, if the results at these two periods are to be compared, we must first determine whether the samples taken represent layers of equal depth and weight in the two cases. Confining attention on the present occasion to the results relating to the first 9 inches of depth, the following figures show the average weight of dry mold per acre, that is, of soil excluding stones and moisture, calculated from the weight of the samples taken, and from the results of the mechanical separation, and of the determination of moisture in the soils.

For 1865, the calculations are based on the results afforded by eighty samples, eight from each of ten of the eleven plots, the eleventh being the one annually receiving farm-yard manure; and for 1881 they are based on the results relating to one hundred and fourteen samples, that is, six samples each from nineteen plots, again excluding the one with farm-yard manure.

Number of samples.	Calculated dry mold per acre.
	Pounds.
1865, 10 plots, eight samples from each	2,298,038
1881, 19 plots, six samples from each	2,552,202

The importance of taking samples of definite area and depth, and of determining the weights, is here strikingly illustrated. Thus, it is obvious that the samples analyzed in 1881 represented, on the average, almost exactly one-ninth more soil per acre than those analyzed in 1865. In other words, if the samples of 1865 fairly represented 9 inches of depth in the average condition of consolidation of the soil, those of 1881 represented 10 inches of soil in the same condition; that is, they included 1 inch more of subsoil, with its much lower percentage of nitrogen than the 9 inches above it. It may, of course, be a question whether the condition of consolidation of the soil was the more normal at the one period or at the other; and it would make scarcely any difference in the relation of the results to one another at the two periods, whether the actually determined percentages of nitrogen in the 1865 samples were lowered on the assumption that they should have included 1 inch more of subsoil, or whether the determined percentages in the 1881 samples are raised on the assumption that they contained 1 inch too much of subsoil. We have concluded, from a consideration of all the facts at command, that the latter alternative is upon the whole the best. We adopt, therefore, the percentages of nitrogen as actually determined in the 1865 samples, and we assume the weight of mold (9 inches deep) represented by the samples to be 2,300,000 pounds per acre. But in the case of the 1881 samples we assume that one-tenth of the heavier weight had the composition determined in the second 9 inches (it would be very slightly higher), and the percentage in the remaining nine-tenths, representing 2,300,000 pounds of surface soil, is raised by calculation accordingly.

The following table (VIII) gives for the surface soils (9 inches deep), of the unmanured plot, and the nine artificially manured plots sampled in 1865, the actually determined percentages of nitrogen in the dry mold, and for the 1881 samples from the same plots, both the actually determined percentages and the corrected percentages, calculated as above described. The table also shows the amount of nitrogen per acre, reckoning 2,300,000 pounds of dry mold, calculated for 1865 according to the

actually determined percentages, and for 1881 according to the corrected percentages. The quantities per acre more (+) or less (—) in 1881 than in 1865 are also given. Lastly, for each period are given the quantities more or less on each of the other plots than on plot 5*a*, which received the mineral manure alone.

TABLE VIII.—BROADBALK FIELD SOILS.

Nitrogen per cent. in the dry mold and per acre.

[Wheat thirty-nine years in succession, 1843–'4 to 1881–'2, inclusive.]

Plots.		Nitrogen.								
		Per cent. in dry mold.			Per acre, 2,300,000 pounds dry mold,					
		1865.	1881.		1865.	1881.	1881 + or — 1865.	+ or — plot 5*a*.		
		Actual.	Actual.	Corrected.				1865.	1881.	1881 +or— 1865.
		Per ct.	*Per ct.*	*Per ct.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
3	Unmanured	0.1090	0.1009	0.1045	2,507	2,404	—103	......	......	......
5*a*	Mixed mineral manure	0.1119	0.0981	0.1012	2,574	2,328	—246	......	......	......
7*a*	Mixed mineral manure and ammonia salts, = 86 pounds nitrogen.	0.1230	0.1207	0.1264	2,829	2,908	+ 79	+255	+580	+325
9*a*	Mixed mineral manure and nitrate of soda, = 86 pounds nitrogen.	0.1232	0.1200	0.1253	2,834	2,883	+49	+260	+555	+295
10*a*	Ammonia salts, = 86 pounds nitrogen (1845 and since).	0.1108	0.1034	0.1074	2,548	2,471	—77	—26	+143	+169
11*a*	Ammonia salts, = 86 pounds nitrogen and superphosphate.	0.1171	0.1121	0.1164	2,693	2,676	—17	+119	+348	+229
12*a*	Ammonia salts, = 86 pounds nitrogen, superphosphate, and soda.	0.1208	0.1155	0.1202	2,778	2,765	—13	+204	+437	+233
13*a*	Ammonia salts, = 86 pounds nitrogen, superphosphate, and potassa.	0.1206	0,1191	0.1245	2,774	2,863	+89	+200	+535	+335
14*a*	Ammonia salts, = 86 pounds nitrogen, superphosphate, and magnesia.	0.1197	0.1163	0.1215	2,753	2,794	+41	+179	+466	+287
16*a*	Ammonia salts, = 172 pounds nitrogen and mixed mineral manure.	0.1264	0.1066	0.1122	2,907	2,557	—350	+333	+229	—104

As already said, in 1865 the land had grown twenty-two crops, and in 1881 thirty-eight crops of wheat in succession. Plot 3 had been unmanured from the commencement. Plot 10*a* received mineral manure in the first year, but the ammonia salts alone each year since. The remaining plots were somewhat variously manured during the first eight of the thirty-eight years; but (excepting plot 16) each has been manured every year for the last three of the thirty-eight years, as discribed in the table.

It will be observed that for every plot, the actual determinations show a lower percentage of nitrogen in 1881 than in 1865. The corrected percentages for 1881 are, of course, all rather higher than the actual determinations, and they, in some cases, show a higher and in others a lower percentage than in 1865. Nevertheless, it cannot fail to be noted that

the rotation of plot to plot is essentially accordant at the two periods. The significance of the results will, however, be rendered the more apparent on an examination of the calculated quantities per acre. It is obvious that absolute accuracy cannot be claimed for such figures, but the general accordance of the indications at the two periods is such as to leave no doubt of their import.

Keeping in view the special object of this communication, which is to show the bearing of what may be called the nitrogen statistics of the soils, on the question of the source of the nitrogen in the crops, it will be seen that during the sixteen years, from 1865 to 1881, both the unmanured plot (3) and the mineral manured plot (5*a*), the yield of nitrogen in the crops of which declined so strikingly, show a great reduction in the stock of nitrogen in the surface soil. The reduction in these later years is considerably greater in the surface soil of the mineral manured than in that of the entirely unmanured plot, the previous accumulation in which had been many more years subject to exhaustion. Taking the results, however, for the first, second, and third 9 inches, the calculated loss to the depth of 27 inches is approximately the same for the two plots. The figures recorded for the first 9 inches only are, however, sufficient to show that the decline in the yield of nitrogen in the crop where none has been supplied in manure, is accompanied by a decline in the stock of nitrogen in the soil.

A further illustration on this point is afforded by the results for plot 16*a*. For the thirteen years, 1852–1864, plot 16 received, besides the mixed mineral manure, twice as much ammonium-salts as any of the other plots, the results for which are given in the table, and it gave on the average of those years 39½ bushels of grain per acre per annum. Since 1864, however, the plot has been left unmanured, and during the seventeen years, 1865–1881, it has yielded an average of only 14¾ bushels of grain; and in recent years the produce has been very little more than without manure, or with purely mineral manure. The table shows that in 1865, that is, after one crop had been removed since the application of the excess of ammonia salts, the surface soil still contained considerably more nitrogen than any other plot in the series. In 1881, however, after sixteen years more of cropping without manure, the stock of nitrogen on the plot was reduced by a greater amount than on any other plot, and to a lower point than on any other of the ammonium plots, excepting plot 10 with the ammonium salts alone.

Let us now refer to the last three columns in the table, which shows for each of the plots receiving ammonium salts the amount of nitrogen per acre in the surface soil, more or less than in that of plot 5*a*, with mineral manure alone. All the plots, 7 to 14 inclusive, received the same quantity of nitrogen, namely, 86 pounds per acre per annum. But it will be seen that the excess of nitrogen in the surface soils compared with the mineral manured plot 5, varies exceedingly; in fact, it is obvious that the amounts have no direct relation to the amount of nitro-

gen supplied in the manure. The following table will afford some explanation of these differences. The plots under consideration, all of which received the same amount of nitrogen in manure, are there given in the order of their average annual increased yield of nitrogen in the crops over plot 5. The first column shows the estimated average annual increased yield of nitrogen per acre in the crops; the second, the estimated annual loss of nitrogen as nitric acid by drainage; the third, the estimated annual excess of nitrogen in the surface soil over that on plot 5 with the mineral manure alone; and the last column shows the relation which that excess in the soil bears to 100 increased yield in the crops.

TABLE IX.—*Estimated nitrogen per acre per annum.*

Plots.		In crops over plot 5.	Loss by drainage over plot 5.	In soil 9 inches deep over plot 5.	Excess in soil to 100 increase in crop.
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
10	Amm. salts = 86 pounds N. (1845 and since)	12.4	31.2	4.8	38.7
11	Amm. salts = 86 pounds N. and superphosphate	17.7	28.5	11.6	65.5
12	Amm. salts = 86 pounds N. superphos. and soda	22.2	24.5	14.6	65.8
13	Amm. salts = 86 pounds N. superphos. and potass	23.4	25.6	17.8	76.1
14	Amm. salts = 86 pounds N. superphos. and mag'a	24.1	27.5	15.5	64.3
7	Amm. salts = 86 pounds N. and mixed min. man	25.9	19.0	19.3	74.5
9	Nit. soda = 86 pounds N. and mixed min. man	26.0	23.7	18.5	71.2

It is seen that the increased yield of nitrogen in the crops also varied exceedingly with the same amount supplied in manure, according to the condition as to supply of mineral constituents. Plot 10, with the ammonium salts alone, gives the smallest increased yield of nitrogen in the crop; and plots 7 and 9, with the most complete mineral manure, each more than twice as much: the other plots giving intermediate amounts. The order of the estimated loss of nitrogen by drainage is almost the converse of that of the increased yield in the crops. Plot 10, which gives the least increased yield in the crop, shows the greater loss by drainage; and plots 7 and 9, which yield the greatest increase in the crop, show the least loss by drainage. The excess in the soils (over plot 5) is obviously much more in the order of the increased yield in the crops. Plot 10, with the least in the increase of crop and the most in the drainage, shows the least excess in the soil, whilst plots 7 and 9, with the greatest increased yield in the crop and the least loss by drainage, show the greatest excess in the soil.

It is clear, therefore, that whilst the excess in the soil has no direct relation to the amount supplied in the manure, it has a very obvious relation to the increased yield in the crop; in other words, to the amount of growth. The last column of the table brings this out more clearly. Excepting in the case of plot 10, with the ammonium salts alone, there is a general uniformity in the proportion of the excess in the soil over plot 5

to the increased yield in the crop over plot 5; and the variations, such as they are, have an obvious connection with the conditions of growth. Thus, plots 11, 12, and 14, all with a deficient supply of potass, show approximately equal proportions retained in the soil for 100 of increase in the crop. Plots 13, 7, and 9, again, all with liberal supplies of potass, show higher, but approximately equal, proportions retained in the surface soil for 100 of increased yield in the crop. Upon the whole, it is obvious that the relative excess of nitrogen in the soils of the different plots is little, if at all, due to the direct retention by the soil of the nitrogen of the manure, but is almost exclusively dependent on the difference in amount of the residue of the crops—of the stubble and roots, and perhaps of weeds.

Recurring to the main point, which it is our object to elucidate, there can be no doubt that the determinations of nitrogen in the surface soils of the different plots of the experimental wheat field, at different dates, establish the fact that the decline in the yield of nitrogen in the crops is accompanied by a decline in the stock of nitrogen in the soil. It will be well to consider as far as the data at command will allow, what relation the yield of the nitrogen in the crops bears to the loss of nitrogen by the soil? On this point it may be stated that, taking the average of thirty years, 1852–1881, it is estimated that the unmanured plot yielded 18.6 pounds of nitrogen in the crops and 10.3 pounds in the drainage, or in all 28.9 pounds per acre per annum over that period. In like manner it is estimated that plot 5, which received nitrogenous as well as mineral manure during the preceding eight years, but mineral manure alone during the thirty years, yielded 20.3 pounds of nitrogen in the crops and 12 pounds in the drainage, or in all 32.3 pounds per acre per annum. It would thus appear that without nitrogenous manure about 30 pounds of nitrogen has been contributed per acre per annum to crop and drainage together. The determinations of nitrogen in the soils of the two plots indicate that they have lost an average of about two-thirds of this amount annually to the depth of 27 inches. There would, therefore, according to this reckoning, remain about one-third—say 10 pounds more or less—to be contributed by seed, by rain, and condensation from the atmosphere, and by all the other supplies of combined nitrogen, which have been supposed to be available, whether of the combination of free nitrogen within the soil, or its assimilation by the plant. Of this amount about 2 pounds will be due to seed, and if we suppose, say, only 5 pounds to be annually supplied by rain and the minor aqueous deposits from the atmosphere, there is but little left to be provided by all the other sources assumed.

NITROGEN IN THE SOILS OF THE EXPERIMENTAL BARLEY PLOTS.

Unfortunately we have not so complete a series of determinations of nitrogen in the soils of the experimental barley plots as of those in the experimental wheat field. In 1868 four of the barley plots were sampled,

four samples, each 6 by 6 inches area, by 9 inches deep, were taken from each plot, and the four mixed together. In March, 1882, 26 plots were sampled, four samples being taken from each plot, each 6 by 6 inches area, and to the depth of three times 9 or 27 inches. Of the plots sampled in 1868 only one had received no nitrogenous manure, but we are able to give the percentage of nitrogen in the surface soil of this plot at the two dates.

TABLE X.—HOOSFIELD BARLEY LAND.

Nitrogen, per cent. in the dry mold, first 9 inches.

[Barley thirty-one years in succession, 1852–1882 inclusive.]

Kind of manure.	1868.	1882.
	Per cent.	*Per cent.*
Mixed mineral manure alone	0.1202	0.1124

The calculated average weights of dry mold per acre, to the depth of 9 inches, were not very different at the two dates. The 1882 samples were, however, slightly the heavier, which would indicate that, for comparison, the percentage of nitrogen given for the later date is perhaps somewhat too low. Still, it is obvious that, as in the case of the wheat land, so also in that of the barley land, there is, with the decline in the yield of nitrogen in the crop at the same time a decline in the stock of the nitrogen in the soil.

NITROGEN IN THE SOILS OF THE EXPERIMENTAL ROOT-CROP PLOTS.

The next results relate to the land upon which root crops—common turnips, swedes, sugar-beet, and mangel-wurzel—have (with the exception of the interpolation of three years of barley) been grown for forty years in succession, 1843–1882 inclusive. Samples of the soil have only been taken once, namely, in April, 1870; that is, after the experiment had been continued twenty-seven years. At that time 35 plots were sampled, and four samples were taken from each plot, each 6 by 6 inches area, and to a depth of 3 times 9 or 27 inches.

The following table shows the percentage of nitrogen in the surface soil of the continuously unmanured plot, and of three plots with mineral manure alone:

TABLE XI.—BARNFIELD ROOT-CROP LAND.

Nitrogen, per cent. in dry mold, first 9 inches.

[Root crops (except barley three years) forty years in succession, 1843–1882 inclusive.]

Kinds of manure.	1870.
	Per cent.
Plot 3.—Unmanured	0.0852
Plot 4.—Mixed mineral manure	0.0934
Plot 5.—Superphosphate alone	0.0888
Plot 6.—Superphosphate and potass	0.0867
Mean of plots 4, 5, and 6	0.0896

Having only taken samples once, we have, of course, no means of comparing the condition of the land as to its percentage of nitrogen at different periods. The point to be observed in the results given in the table is, that each of the four plots which have received no nitrogenous manure shows, after twenty-seven years of experiment (twenty-four years roots and three years barley), a lower percentage of nitrogen in the surface soil than has been found in any of the other experimental fields, though determinations made in samples from other parts of the same field, and also in an adjoining field, show considerably higher results. The nearest approach to so low an amount in any other field is where the land had been under alternate wheat and fallow for more than thirty years.

It will be remembered that the root crops gave with mineral manure alone a very much higher yield of nitrogen than the cereals in the earlier years and as low a yield in the later years. That they did not give less still is probably owing to the fact that their growth extends later in the season than the cereals, by virtue of which they are probably enabled to arrest the nitric acid formed within the soil during the autumn months, which in the case of the cereals would be more subject to loss by drainage.

Both the mechanical conditions of surface soil known to be favorable for the growth of the root crops, and the large amount of fibrous root they throw out near the surface, indicate an active demand on the resources of the upper layers of the soil, and are perfectly consistent with the supposition that their growth has led to a greater reduction in the stores of nitrogen of the superficial layers than in the case of any of the other crops.

The evidence afforded both by the facts of production and the determinations of nitrogen in the soil are indeed strongly in favor of the view that the source of the nitrogen of the root crops, as of the cereals, is, when grown without nitrogenous manure, the soil itself, and the small quantity of combined nitrogen annually contributed by rain, and the minor aqueous deposits from the atmosphere. It is said, however, that these crops require a certain amount of nitrogen to be supplied by manure, and that they then are able to take up the remainder from atmospheric sources. The facts of production recorded at page 7 afford no countenance to such a view. We conclude, indeed, that the dependence of these crops for their nitrogen, on the stores of the soil itself, or on supplies by manure, is as clearly established as in the case of the cereals.

IS THE SOIL A SOURCE OF THE NITROGEN OF THE LEGUMINOSÆ?

We have now to consider the bearing of the evidence on the question of the source of the nitrogen of the leguminosæ, and here we approach not only the most important but the most difficult part of our subject.

The first of the leguminous crops, the yield of nitrogen in which is recorded in Table I. is beans. Without manure the yield of nitrogen

was in the earlier years very much higher than with the cereals; but the decline was very great, and in the later years it was as low as with the cereals. With mixed mineral manure, including potass, the yield was throughout much higher, but the decline was, as without manure, very great. We have not a sufficiently comparative series of determinations of nitrogen in the soils of the bean plots, but such results as are at command lead to the conclusion that there has been a gradual decline in the percentage of nitrogen in the surface soils; but, considering the little tendency of the plant to throw out feeding root in the superficial layers, it may be a question how far the reduction is due to exhaustion by the direct action of growth, or how far to nitrification and passage of the nitrates downwards.

NITROGEN IN THE SOILS OF THE EXPERIMENTAL CLOVER-PLOTS.

The most important of the leguminous crops to which reference has been made is red clover. In Table I is recorded the yield of nitrogen over twenty-two years, in only six of which, however, was any crop obtained. The experiment has been continued with some modifications, and in 1877, that is after thirty years, in nine of the last ten trials the plant had died off during the winter and spring succeeding the sowing of the seed. Several small crops have since been obtained, and in March, 1881, samples of soil were taken from five places where no nitrogenous manure has been applied from the commencement, and at each place to three depths of 9 inches each. Exactly corresponding samples were also taken from an immediately adjoining plot, which had been thirty years under alternate wheat and fallow, without manure of any kind. The nitrogen was determined in each of the five separate samples, and also in the mixture of the five. Table XII summarizes the results.

TABLE XII.—HOOSFIELD CLOVER AND WHEAT AND FALLOW LAND.

Nitrogen, per cent. in dry mold, first 9 inches.

[Experiments more than thirty years.]

Mean.	1881.	
	Clover land.	Fallow land.
	Per cent.	*Per cent.*
Mean on five separate samples	0.1067	0.0925
Mean on mixture of five samples	0.1055	0.0984
Mean	0.1061	0.0955

It is true that the tendency of the evidence on the point is to show that red clover derives, at any rate, much of its nitrogen from the lower layers of the soil; but it is surely significant that, after the growth of heavy crops in 1849, when the land was in ordinary condition as to

manuring, and the constant failure since, there is coincidently with this nearly as low a percentage of nitrogen in the surface soil as with alternate wheat and fallow without manure. It is obvious that any accumulation near the surface, due to residue from the small crops, has been more than compensated by exhaustion. The evidence offered by the figures may be said to be of a somewhat negative character; but it is at any rate clear that failure of growth has been associated with a declining and very low percentage of nitrogen in the surface soil.

The next results are of a very much more definite character. They relate to the two portions of the field which had grown six corn crops in succession by artificial manures alone, was then divided (in 1873), and on one half clover and on the other half barley was grown. Table I shows that in the clover crops 151.3 pounds, and in the barley only 37.3 pounds of nitrogen were removed. Yet in the next year, barley being grown over both portions, the one which had yielded 151.3 pounds in clover now yielded 69.4 pounds in barley; and the other, which had yielded only 37.3 in barley, now yielded only 39.1 pounds in barley.

In October, 1873, after the clover and barley had been removed and before the land was plowed up, samples of the soil were taken as follows: From each portion four separate samples, each 12 by 12 inches area and 9 inches deep, and the nitrogen was determined in each separate sample and also in an equal mixture of the four. Six other samples, each 6 by 6 by 9 inches, were also taken from each of the two portions, and the six samples representing each portion were mixed, and the nitrogen determined in the mixture. At each place corresponding separate samples were taken and mixtures made, representing respectively the second and the third 9 inches of depth. In all cases three and in many four determinations of nitrogen were made on each sample. The following table gives the mean results on the four separate samples, the mean on the mixture of the four, and the mean on the mixture of the six:

TABLE XIII.—*Experimental clover and barley land.*

Mean.	1873. Clover land.	1873. Barley land.
	Per cent.	*Per cent.*
Mean on four separate samples (12 by 12 by 9)	0.1554	0.1411
Mean on mixture of four samples (12 by 12 by 9)	0.1566	0.1387
Mean on mixture of six samples (6 by 6 by 9)	0.1578	0.1450
Means	0.1566	0.1416

The accordance of the three sets of determinations for the clover land and for the barley land, respectively, can leave no doubt whatever that there was a considerably higher percentage of nitrogen in the first 9 inches of the clover ground than the same depth of the barley ground. The re-

sults must, indeed, be accepted as indicating a marked distinction in the direction which is entirely consistent with what is known of the influence of a clover crop as a preparation for a succeeding cereal one, and entirely consistent with the results actually obtained with the barley succeeding the clover. It is, however, very difficult to suppose that the figures correctly represent in degree the average difference in the composition of the first 9 inches of the two plots, for, calculated per acre, the excess of nitrogen in the surface-soil of the clover plot would represent an accumulation equal to twice as much as was removed in the three cuttings of the clover, notwithstanding all visible vegetable *débris* was removed before the soils were submitted to analysis; nor have the subsequent crops benefited as much as would be expected from such an amount of accumulation. On the other hand, samples taken in 1877 still show a higher percentage of nitrogen in the surface soils of the clover plots.

It is, at any rate, obvious that the surface soil of the clover ground has gained nitrogen either from above or from below—from the atmosphere or from the subsoil; and, so far as the determinations of nitrogen in the subsoil go, the indication is that if from below it is mainly at least from a lower depth than 27 inches. It is freely admitted that in the facts of this experiment as they stand there is no evidence as to the source of the large amount of nitrogen of the clover crop and of the increased amount of it in the surface soil. In the absence of such evidence it is natural enough to assume that the atmosphere has been the source; but whilst there is absolutely nothing in favor of this view excepting the fact that an explanation is needed, and that if that source were established the difficulty would be solved, there is, to say the least, much more evidence in favor of the supposition that the subsoil has been the source of at any rate much of the nitrogen.

THE SOILS OF THE MELILOTUS LEUCANTHA AND WHITE-CLOVER PLOTS.

Reference has already been made elsewhere to the enormous growth of *Melilotus leucantha* and the enormous amount of nitrogen it yielded for several years in succession on the land where no nitrogen had been applied for more than thirty years, and where red clover had so frequently failed. The crop of 1882 was higher still, and the yield of nitrogen in it would certainly exceed 100 pounds per acre; whilst under exactly similar conditions ordinary red and white clover gave very small produce. Accordingly, as soon as the crops were removed, samples of soil were taken from one of the *melilotus* plots and from the corresponding white clover plot. Samples were taken from two places on each plot, and in each case to the depth of six times 9 inches, or in all 54 inches. The examination of these samples of soil is as yet very incomplete, but the following interesting facts have been ascertained:

Whilst the strong roots of the *melilotus* were found to penetrate to the lowest depths of the sampling, there was very little development of

white clover roots beyond the surface soil. Whilst to the eye and to the hand the subsoil where the *metilotus* had grown was pumped dry, and was somewhat disintegrated, to the full depth sampled, that of the clover plot had no such character. Determinations in the soils and subsoils show at each of the six depths much less water in the *melilotus* than in the white-clover soils: and the difference is by far the greater in the lower depths. Calculated per acre, it would appear that to the depth of 54 inches the *melilotus* soil had lost approximately 450 tons more water per acre than the white-clover soil; and there can be no doubt that the pumping action had extended deeper still.

There is here, then, clear evidence that the plant whose habit of growth, and especially whose range and feeding capacity of root, suited it to the conditions, was enabled to take up much more water, and doubtless with it much more food, than, under exactly similar conditions of soil, were at the command of the plant of the much weaker development.

That the deep-rooting *melilotus* did derive more nitrogen from the subsoil than the shallow-rooting white clover is obvious from the following facts: Watery exhausts were made of each soil, at each depth, and the nitrogen as nitric acid determined in them.* The following table summarizes the results:

TABLE XIV.—*Nitrogen as nitric acid.*

	Per million, dry soil.		Per acre.		
	Melilotus soil.	White-clover soil.	Melilotus soil.	White-clover soil.	Difference.
			Pounds.	*Pounds.*	*Pounds.*
First 9 inches	1.25	3.19	3.33	8.42	5.09
Second 9 inches	0.35	1.07	0.95	2.89	1.94
Third 9 inches	0.20	0.64	0.56	1.79	1.23
Fourth 9 inches	0.31	1.00	0.96	2.99	2.03
Fifth 9 inches	0.27	1.40	0.84	4.38	3.54
Sixth 9 inches	0.53	1.69	1.65	5.31	3.66
Total			8.29	25.78	17.49

Thus the *melilotus* had not only exhausted the water, but the nitric acid of the soil at each depth very much more than the white clover had done, and the difference is especially marked at the lower depths. It is seen that in the case of the white-clover soil there is a diminishing amount of nitric acid from the first to the third depth, and then an increasing quantity to the sixth depth. It may fairly be supposed that there is greater concentration lower still, and that the exhausting action of the *melilotus* extended beyond the depth examined.

There is here direct evidence that the subsoil is the source of at any rate some of the excess of nitrogen of the *melilotus* over that in the white clover. The quantity and the distribution of nitric acid in the soil

*As nitric oxide, by its re-action with ferrous salts.

at any one time are so dependent on temporary conditions that it would be fallacious to attempt to estimate from the figures as they stand the exact amount which the *melilotus* has taken up more than the white clover. Then it is obvious that the action extended below the depth examined, and it is a question whether, with the greater disintegration and greater aeration, nitrification would not be favored in the lower depths, and if so the supply would be in a sense cumulative. Lastly, it may be that the deeply and widely distributed *melilotus* roots have the capacity of taking up nitrogen from the subsoil in other forms than as nitric acid.

NITROGEN AS NITRIC ACID IN OTHER SOILS AND SUBSOILS.

It will be some further aid in judging of the possibility or probability that the nitric acid in the soil and subsoil may be an adequate source of the nitrogen of the Leguminosæ, if we quote a few results indicating the amount of nitric acid found in soils under known conditions.

In the first place three soil drain-gauges, one with 20, one with 40, and one with 60 inches depth of soil, in its natural state of consolidation, and each of one-thousandth of an acre area, have been under experiment for between eleven and twelve years. No manure has been applied to these soils from the commencement: the drainage has been regularly collected and measured, and for nearly the whole of the last five years the nitric acid has been determined in monthly average samples of the drainage waters. Taking the result of the three gauges, for four harvest years (from September to August) these soils, which had been about six years without any manure at the commencement of the period under consideration, have lost by drainage an average of 42 pounds of nitrogen as nitric acid per acre per annum, of which perhaps not much more than 5 pounds would be due to rain and condensation of combined nitrogen from the atmosphere. In fact, from 30 to 35 pounds have been annually due to the nitrification of the nitrogenous matter of these unmanured soils. It has to be borne in mind, however, that the blocks of soil having access of air from below as well as from above, the nitrification may have been freer than it would be in soil in its ordinary condition.

Again, in some of the samples of soil taken from the plots in the experimental wheat field in October, 1865, and in many of those taken in October, 1881, that is in each case about two months after the removal of the crop, the nitric acid has been determined. In the case of one plot sampled in 1865, determinations made in 1866 (by Dr. Pugh's method) showed between 60 and 70 pounds of nitrogen as nitric acid per acre to the depth of 27 inches. In the samples of 1881 the amount of nitric acid found represented from under 30 to over 50 pounds of nitrogen per acre in that form, down to the depth of 27 inches, where ammonia and salts or nitrate had been applied for the previous crops. As in the case of the white-clover land, the amount decreased from the

first to the third 9 inches of depth from the surface, and if as in that case, it increased in the lower depths, we have evidence of a considerable store of nitric acid available for such plants as, by virtue of their habit of growth, are able to gather up the residue accumulated within the subsoil.

Determinations made in samples collected in the experimental rotation field in September, 1878, showed the following amounts of nitrogen as nitric acid per acre to the depth of 18 inches:

	With superphosphate only.	With full complex manure.
	Pounds.	*Pounds.*
After fallow	36.3	48.8
After beans	10.6	20.5
Difference	25.7	28.3

Samples collected at the same date from the unmanured alternate wheat and fallow plots showed to the same depth:

	Pounds.
After fallow	33.7
After wheat	2.6
Difference	31.1

Lastly, two fields which had been manured and cropped in the ordinary course of the farm, and had been fallowed since the previous autumn, showed the following amounts of nitrogen as nitric acid per acre to the depth of 27 inches:

	Pounds.
Clay croft field	58.8
Foster's field	56.5

It will be seen that in none of the cases cited is the amount of nitric acid found in the soils to the depth examined, sufficient to account for so large an accumulation in crop and in the surface soil as the figures relating to the nitrogen in the produce of clover, and in the clover and barley soil would indicate had been accumulated. The amounts of nitric acid formed, or remaining, within a limited depth from the surface, at any one time, is, however, as already intimated, dependent on so many temporary circumstances, that it is not to be expected that the amount formed within such limits at any given time would represent more than a fraction of that which would be available even within that range during the long period of growth of the clover crop. Then, the indications are that there is a considerable accumulation beyond the depth to which most of our examinations apply. And there still remains the question whether the roots of the plant do not take up nitrogen from the subsoil in other states than as nitric acid.

Finally in regard to the experiments with clover and barley, it is ad-

mitted that the various results of soil examinations which have been adduced do not conclusively show the source of the whole of the nitrogen to have been the soil. It will, we think, nevertheless be granted, that they do clearly point to the fact that at any rate much of it is derived from that source; whilst there is no evidence whatever of an atmospheric source of more than the small amount of combined nitrogen coming down in rain and the minor aqueous deposits, and the probably still smaller amount absorbed from the atmosphere by porous soil.

NITROGEN IN SOME OF THE SOILS OF THE EXPERIMENTAL MIXED HERBAGE PLOTS.

The results next to be referred to will afford additional evidence of the soil-source of the nitrogen of the Leguminosæ.

In Table 3 it was shown that in the mixed herbage of permanent grass land, without manure 33.0 pounds, and with a purely mineral manure (including potash) 55.6 pounds of nitrogen were yielded per acre per annum in the crop over a period of twenty years. Whence comes the 22.6 pounds more nitrogen per acre per annum taken up when the mineral manure was applied than without manure?

After twenty years of continuous experiment samples of soil were taken from three places on each plot, and in each case to the depth of six times 9 inches, or 54 inches. The mean results of the determinations of nitrogen in the surface soils are given in Table XV which follows:

TABLE XV.—EXPERIMENTS ON PERMANENT MEADOW LAND.

Nitrogen, per cent. in dry mold and per acre.

	1870.	1876.	1878.
	Per cent.	*Per cent.*	*Per cent.*
	0. 2517	0. 2466	....
	....	0. 2236	0. 2246
Difference	....	0. 0230	....
		Pounds.	
Difference per acre { Total twenty years	....	506. 0	....
Difference per acre { Average per annum	....	25. 3	....

Although we have not previously quoted the figures we have on several occasions stated in general terms that determinations of nitrogen in the soils show a lower amount in the mineral manured soil, approximately corresponding to the increased yield in the crop; and it is in reference to our statements on this point that M. Joulie has called in question the possibility of obtaining results of the kind applicable to our argument. He takes the fact of the increased yield of nitrogen under the influence of purely mineral manure as conclusive proof of the atmospheric source of the increased amount of nitrogen assimilated. He assumes that our calculations are based on determinations of nitrogen in a sample of the mixed soil to the total depth of 54 inches. He calculates that in the mass of soil to that depth the difference in the

amount in the two cases would be far too small to furnish a justification for the important conclusion that the soil was the source of the nitrogen; and he objects that the roots of such herbage would derive their nutriment chiefly in the superficial layers. He further objects that if the difference we assume were a fact, it is probably due to an accidental difference in the soil of the two plots, such a difference having been admitted by us in the case of another plot. Lastly, he suggests that if there really were the reduction we suppose, it might be due to other causes—such as increased activity of nitrification under the influence of the mineral manure and passage of the nitrates downwards.

In the first place, in the case of the irregularity in the condition of one of the plots referred to, the difference was readily seen in the section of the soil, and there was no such difference in the instance now under consideration.

Then it is the determination of nitrogen in the first 9 inches of soil alone, to which we have hitherto referred, and to which we confine attention on the present occasion.

In the next place, that the difference in the condition of the two plots is not merely local is shown by the fact that the determinations on a sample from the unmanured plot taken in 1870 entirely confirm the relative composition shown by the samples of 1876. Again, the lower percentage of nitrogen in the 1876 samples of the mineral manured plot is entirely confirmed by the results obtained on samples taken in 1878. Further, of the twenty experimental plots, there is only one other showing anything like so low a percentage as the mineral-manured plot, and that is the one which has received the same mineral manure, but for a shorter series of years.

We have in fact no doubt whatever that the differences shown by the figures are real and dependent on the conditions of manuring and of growth. The reduction is, moreover, very great, amounting to nearly one-tenth of the total quantity of nitrogen, an amount far beyond the limits of accidental difference in the sampling or the analysis.

Calculated per acre, the surface soil of the mineral-manured plot contained, at the end of the twenty years, 506 pounds less nitrogen than the soil of the unmanured plot to the same depth, corresponding to an annual reduction of 25.3 pounds of nitrogen per acre per annum. It is, to say the least, a very remarkable coincidence that the increased yield of nitrogen on the mineral-manured plot which has to be accounted for is 22.6 pounds per acre per annum.

We do not pretend to claim absolute accuracy for such results, but we ourselves entertain no doubt whatever of their significance and their importance. It will be asked, How is it that in the case of the red clover and the *melilotus* it was concluded that, so far as the plants had derived their nitrogen from the soil, it was at any rate mainly from the lower depths, and that here we assume the increased yield of nitrogen to be derived from the surface soil?

Under the influence of the mineral manure a larger proportion and

amount of leguminous herbage was developed than on any other plot, but the leguminous plant the most and indeed very prominently favored was the *Lathyrus pratensis*, which throws out an enormous quantity of root near the surface; and it is sufficiently established that the potash of artificial manures remains almost exclusively in the superficial layers. On the other hand, the perennial red clover and the *Lotus corniculatus*, which have a much more deeply-rooting tendency, are comparatively little encouraged. The actual amount of leguminous herbage produced, however, is not sufficient to account for nearly the whole of the increased yield of nitrogen in the produce of the plot. The fact is that besides a proportionately very large increase in the growth of leguminous herbage, there has been a gradually increasing amount of gramineous produce developed; far beyond what would be anticipated from the extremely limited effect of such manures on gramineous crops grown separately on arable land. How far this result may be due to the much more active nitrification induced under the influence of the mineral manure in the much more highly nitrogenous grass land than in the poorer arable soil, and so yielding a direct supply to the graminæ of the mixed herbage, or how far to an increased supply in a condition available for the grasses as the result of the increased growth of the Leguminosæ, may be a question. But it is of interest to note that the gramineous species that are developed are among the most superficially rooting of the grasses found on the experimental plots.

Before leaving the subject of these experiments on the mixed herbage of grass land, it may be well to call attention to the fact that, on the assumption that the whole of the nitrogen of the herbage, beyond the small amount of already combined nitrogen contributed by rain and condensation from the atmosphere, is derived from the soil, we have to conclude that about 25 pounds per acre per annum have been yielded by the soil of the unmanured plots, and nearly an additional 25 pounds, or in all about 50 pounds, from the mineral-manured plot. It was estimated that, in the case of the continuous wheat experiments, about 20 pounds of nitrogen had been annually obtained in the crop, and a minimum of 12 pounds lost by drainage; in all 32 pounds. It cannot fail to be observed how closely this amount corresponds with the annual yield of nitrogen in the unmanured mixed herbage. With the richer grass land, though less aerated than arable land, it might be expected there would be some increased activity of nitrification, even in the unmanured soil, and there may be some loss by drainage; but, with a mixed herbage of some 50 species of very varying habit of growth, and with the possession of the soil all the year round, it is only what would be expected that there would be more of the available nitrogen taken up by the crop and less lost by drainage than with the cereal grown separately on arable land, and occupying the soil for only a very limited period of the year.

We conclude, then, that the results relating to the two mixed herbage

plots can leave little doubt that the increased yield of nitrogen in the more highly leguminous produce of the mineral-manured plot had its source in the stores of the soil itself.

SOURCE OF THE NITROGEN OF CLOVER GROWN ON RICH GARDEN SOIL.

We have one more illustration to bring forward having an important bearing on the question at issue.

In view of the signal failure in the attempt to grow red clover on a nitrogen exhausted arable soil, it is of much interest that large, though declining, crops have been grown for twenty-nine years in succession on a plot of rich kitchen-garden soil.

The experiment was commenced in 1854, and the following table shows the percentage of nitrogen in samples of the first 9 inches of soil taken in October, 1857, and in May, 1879; that is, with an interval of twenty-one seasons of growth. In 1857 only one sample was taken, and only to the depth of 9 inches, but in 1879 three samples were taken, in each case to the depth of twice 9, or 18 inches:

TABLE XVI.—CLOVER GROWN ON KITCHEN-GARDEN SOIL.

Nitrogen, per cent. in dry mold and per acre.

	1857.	1879.	Difference.
	Per cent.	*Per cent.*	*Per cent.*
	....	0.3635	....
	....	0.3640	....
	....	0.3626	....
	0.5095	0.3634	0.1461
	Pounds.	*Pounds.*	*Pounds.*
Per acre, total	10.190	7.268	2.922
Difference per acre per annum	....	....	0.139

The percentage of nitrogen given for the single sample collected in October, 1857, is the mean of determinations made in 1857, 1866, and 1880, and is almost identical with the mean of those made at the latest date. The first point to observe is that the first 9 inches of the garden ground contained more than half a per cent. of nitrogen, about four times as much as the average of the arable soils, and nearly five times as much as the exhausted clover-land soil. It is of course true that the soil would be correspondingly rich in all other constituents; but some portions of the arable soil where clover failed, had received much more of mineral constituents by manure than had been received in the crops.

The means of the determinations made on the three separate samples taken in 1879 agree very well, and the results can leave no doubt whatever that there has been a great reduction in the stock of nitrogen in the surface soil. The reduction amounts to about 29 per cent. of the total, and, reckoned per acre, as shown at the foot of the table, it corresponds to a loss of 2.922 pounds during the twenty-one seasons of growth; and although really good crops are still grown in most years, there has been, with this great reduction of the stock of nitrogen in the soil, a very marked reduction in the clover-growing capability of the

soil. Thus, during the first fourteen of the twenty-nine years of the experiment, seed was sown only three times, whilst during the last fifteen years it has been necessary to sow ten times. It is obvious, therefore, that the plant stood very much longer during the earlier than the later years. Then, again, the produce from the three sowings during the first fourteen years was nearly twice as much as has been obtained since.

The question obviously arises, what relation does the amount of nitrogen lost by the soil bear to the amount taken off in the crops? We quite admit the uncertainty of calculations of produce per acre from the results obtained on a few square yards. We are, however, disposed to estimate the average yield of nitrogen over the twenty-one years at about 200 pounds per acre per annum. The table shows that against this we have an estimated loss of nitrogen by the first 9 inches of soil of 139, say 140, pounds per acre per annum, corresponding approximately to three-fourths of the amount estimated in the crop.

There is, however, evidence leading to the conclusion that, at any rate in the case of arable soils containing an unusually high percentage of nitrogenous organic matter, there may be a loss by evolution as free nitrogen; and, obviously, so far as this may have occurred in the garden soil, there will be the less of the determined loss to be credited to assimilation by the growing clover. On the other hand, it is known that when growing on ordinary arable soil, the clover plant throws out a large amount of roots in the lower layers, and although in the case of so rich a surface soil, the plant may derive a larger proportion of its nutriment from that source, we must at the same time suppose that it has also availed itself of the resources of the subsoil. Unfortunately, we did not sample deeper than 9 inches in 1857, so that we can make no comparison of the condition of the subsoil at the two periods. It may, however, be observed that in 1879 the second 9 inches showed about three times as high a percentage as the subsoils of the arable fields at the same depth; indeed, not far from twice as high a percentage as several of the exhausted arable surface soils. It cannot be doubted, therefore, that the subsoil of the garden plot has contributed to the yield of nitrogen in the crop.

If, then, we have not here absolute proof that the source of the whole of the nitrogen of clover growing on the garden soil was the soil itself, we have surely very strong grounds for concluding that much of it has been so derived.

GENERAL CONCLUSIONS.

In fact, after this review of the evidence which the determinations of nitrogen in the soils of our experimental plots afford, we end, as we began, by saying that, although we admit the facts of production are not yet conclusively explained, we maintain that there is, to say the least, much more of direct experimental proof of the soil than of the atmospheric source of the nitrogen. Moreover, we submit that this

may be said not only of the source of the nitrogen of the cereals, but of the root crops and of the Leguminosæ.

If, on the other hand, the atmosphere is the main, if not the exclusive, source of the nitrogen of the Leguminosæ, we would ask here, as we have asked elsewhere, why those leguminous crops which take up the most nitrogen can be less frequently grown on the same soil? Why we entirely failed to grow clover successively on ordinary arable land, which was nevertheless in a condition to yield fairly good corn crops? Why the only condition under which we have been able to grow clover continuously was where the soil was very much richer in nitrogen (and of course in other constituents also) than the arable land? And lastly, why its growth under such circumstances has been accompanied by a rapid diminution in the amount of nitrogen in the soil, and with this a marked decline in the produce?

It will not for a moment be supposed that because in the foregoing illustrations and arguments we have confined attention almost exclusively to the nitrogen in the soils, we in any way ignore the importance of a liberal available supply of the mineral constituents, so essential for the effective action of the nitrogen. There is abundant evidence, however, that the failures that have been cited have not been due to a deficiency of such constituents.

If, then, the supply of mineral constituents not being defective, the yield of our crops is in the main dependent on the amount of nitrogen which is available to them within the period of their growth, surely the fertility of a soil must be largely measured by the amount of nitrogen it contains and the degree in which it becomes available. And if this be so, is not the soil a mine as well as a laboratory?

In this connection, speaking here in America, it will not be inappropriate to conclude with a brief reference, such as the limited data at our command will permit, to what we believe must be a characteristic difference between the comparatively recently or even not yet broken up soils of this continent, and those which have been long under arable culture on the other side of the Atlantic.

A sample of Illinois soil obtained some years ago by Mr. (now Sir) James Caird, and submitted by him for analysis to Dr. Voelcker, to whom we are indebted, not only for his own analytical results, but also for a sample of the soil itself, shows, by almost identical results in the two laboratories, very nearly 0.25 per cent. of nitrogen. We have no history of this soil, nor do we know the depth to which it was taken, but Dr. Voelcker informs us that the sample supplied to us was a mixture of both soil and subsoil as supplied to him, and in the separate surface soil he found 0.33 per cent. of nitrogen.

During the present year between forty and fifty samples of soil from the Northwest Territory, taken at intervals between Winnipeg and the Rocky Mountains, were sent over to the High Commissioner in London, and exhibited at the recent show of the Royal Agricultural Society

of England, at Reading. The soils were exhibited in glass tubs 4 feet in length, and are stated to represent the core of soil and subsoil to that depth. Three samples of the surface soils have kindly been supplied to us for the determination of the nitrogen in them:

No. 1 is from Portage le Prairie, about 60 miles from Winnipeg, and has probably been under cultivation for several years. The dry mold contained 0.2471 per cent. of nitrogen.

No. 2 is from the Saskatchewan district, about 140 miles from Winnipeg, and has probably been under cultivation a shorter time than No. 1. The dry mold contained 0.3027 per cent. of nitrogen.

No. 3 is from a spot about 40 miles from Fort Ellis, and may be considered a virgin soil. The dry mold contained 0.2500 per cent. of nitrogen.

In general terms it may be said that these Illinois and Northwest Territory surface soils are more than twice as rich in nitrogen as the average of the Rothamsted arable surface soils, and, so far as can be judged, probably twice as rich as the average of arable soils in Great Britain. They indeed correspond in this respect very closely with the surface soils of our permanent pasture land. As this nitrogen has its source in the accumulation from ages of natural vegetation, with little or no removal, it is to be supposed that, as a rule, there will not be a relative deficiency of the necessary mineral constituents. Surely, then, these new soils are mines as well as laboratories! If not, what is the meaning of the term *a fertile soil?*

But, assuming these soils not to be deficient in the necessary mineral supplies, and that they yield up annually in an available condition an amount of nitrogen at all corresponding to their richness in that constituent, it may be asked whether they should not yield a higher average produce of wheat per acre than they are reported to do? The exhausted experimental wheat field at Rothamsted, the surface soil of which at the commencement of the experiments thirty-nine years ago probably contained scarcely half as high a percentage of nitrogen as the average of these four American soils, yielded over the first eight years $17\frac{1}{2}$; over the next fifteen years, $15\frac{1}{4}$; over the last fifteen years (including several very bad seasons), only $11\frac{1}{8}$ bushels; and over the whole thirty-eight years about 14 bushels per acre per annum. So far as we are informed, the comparatively low average yield of the rich Northwest soils is largely due to vicissitudes of climate, but largely, also, to the luxuriant growth of weeds, which neither the time at command for cultivation nor the amount of labor available render it easy to keep down. Still, if there be any truth in the views we have advocated, it would seem it should be an object of consideration to avoid, as far as practicable, this great source of reduction of the fertility of these now rich soils.